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CONTRIBUTIONS TO THE HISTORY OF ENGLISH OPTICIANS IN THE FIRST HALF OF THE NINETEENTH CENTURY (WITH SPECIAL REFERENCE TO SPECTACLE HISTORY)

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ABSTRACT. Although London opticians during the 18th century had carried out really splendid work as craftsmen, they were not very quick at adopting new ideas. This was a great drawback, especially as about 1818 Fraunhofer succeeded in raising the standard of his factory to quite an unrivalled height. Although Fraunhofer's innovations do not seem to have had any direct influence on English opticians, they were acknowledged by English scientists. Strenuous endeavours were made between 1826 and 1829 by Sir John Herschel and Michael Faraday to produce optical glass, and splendid theoretical work was carried out by Airy, Coddington, and Hamilton. London opticians, however, did not derive the same amount of help from such scientific innovations as the Vienna school did from Stampfer and Prechtl, who were then professors at the Vienna Polytechnic Institute. There it was possible, from 1826 onwards, to raise the standard of the best craftsmen to a very respectable height, nearly to that of the Benediktbeurn-Munich craftsmen, and the good fortune of securing Petzval's help gave, in 1840, the leading position in the manufacture of photographic lenses of high aperture to the Viennese firm of Voigtländer. The great inventions of stereoscopy and photography presented opticians with quite new problems, and English amateurs were the first to understand photographs as perspectives of the depicted object. At the end of the period discussed in this paper a well directed optical glass factory was established in England.

INTRODUCTION

WHEN I was informed by Mr T. Smith that this Society would be glad to receive a further contribution to the history of English opticians, I had much pleasure in agreeing to prepare a lecture on this subject, not that I was already in possession of subject-matter almost suitable for presentation, but because I hope to win from amongst you workers in this sphere—workers who, I honestly trust, will fill in

the numerous gaps left by me and expand my unpretentious contributions to a real history of this period.

When we considered a few years ago (48) the history of spectacles up to the commencement of the 19th century, we had occasionally to go back to the general history of optics, since it is only by the experience in the manufacture of achromatic telescopes that we can explain the like superiority of the London masters in the production of spectacles, which was freely acknowledged by contemporary opticians of other countries.

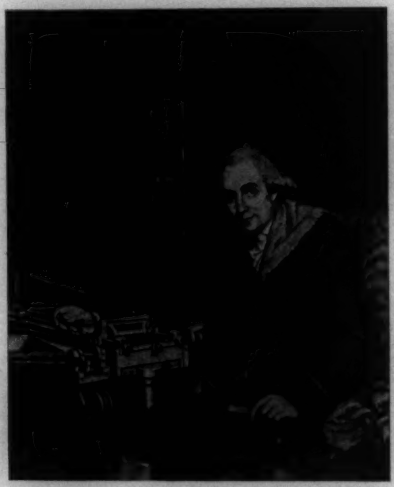


Fig. 1. Jesse Ramsden (b. 1735, d. 5th Nov. 1800), after J. Jones's large copper engraving of 1791 in the Jena collection.

English Opticians and the Manufacture of Telescopes and Spectacles (Periscopic and Bifocal Spectacles and First Monocles)

It is quite true to say that towards the conclusion of the 18th century the position of the English optical industry was superior to that of the neighbouring countries. Soon after the first quarter of this century, however, the London opticians had become trained in careful production of mirror telescopes with more or less perfect paraboloidal surfaces (10), and when Chester Moor Hall's brilliant suggestion (37) found a corresponding application through the firm of Dollond, there were evidently competent men like J. Ramsden (Fig. 1) and S. Pierce, who were

capable of the successful management of their own workshops. Thus it came about that all these skilled masters more or less disregarded the spectacle trade, though incidentally very high prices (64) pertained in the rich metropolis. Drawing from our knowledge of the different centuries, in the earlier ones (44) of which reigning princes and the rich nobility had had great joy in magnificent spectacles and did not shy at a great outlay, the trade of fortunate London certainly rose to its highest in this respect towards the end of the 18th century.

Thus the remuneration may have induced business men like W. Cary to give some attention also to the sale of spectacles, although nowadays we would regard the status of this person more as that of a mechanic highly skilled in telescope construction (38). Apart from his recognised performances in his principal occupation, he has, however, great merit in the unassuming branch concerned with spectacles; this much we know, that he was the first ((72), p. 39) to notice visual disturbances due to astigmatism among his customers, especially those who were short-sighted, in that it was apparent that those spectacle wearers were prone to

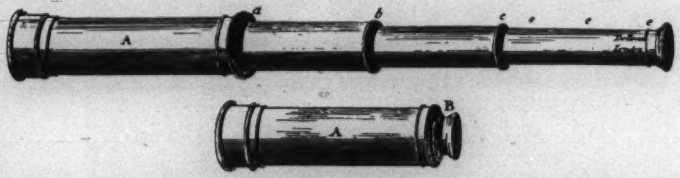


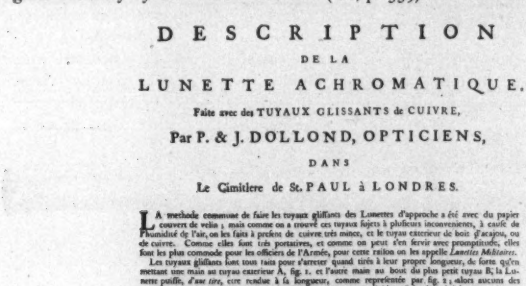
Fig. 2. P. and J. Dollond's military telescope, brought out not before 1782, after the specimen in the Jena collection.

look through glasses placed obliquely. As we would say nowadays, they used the astigmatism of the oblique ray-bundles to compensate the total astigmatism along their visual axis. On account of what follows, we will merely mention here that Thomas Young was content to use this make-shift means, which does not give a particularly large field of view, as his astigmatic eye permitted very precise observation without further aid. This very gifted and learned man's optician thus did not acquire from him any information as to a better method of overcoming this visual defect.

Surveying once more the sphere of activity of the London opticians, the chief sale, in addition to spectacles, was of telescopes. Theatre-glasses (43) and "perspectives" or "prospects" with achromatic (incidentally, also with simple) objectives were sold at good prices and, by the beginning of the 19th century at least, their external dimensions had been considerably reduced by the introduction of a number of draw-tubes sliding one within the other. As to this, reference may be made to the patent (71) of W. Worris in 1804. In this warlike period the English optician no doubt laid great value upon the large draw-telescope (Fig. 2), which was already termed by the firm of Dollond about 1780 the "Army telescope" (55) (Fig. 3). Though no doubt the English output of useful pieces of flint glass had

declined towards the 60th and 70th years of the previous century (58, p. 279), nevertheless appropriate pieces were immediately obtainable for the small objectives of such hand-telescopes, and the English craftsmen were of recognised training in the manufacture of the lenses and in the preparation of good sliding brass tubes.

These easily portable hand-telescopes had practically completely displaced the old stand-telescope with mirror arrangement of the Gregory type, a result which follows from ordinary everyday use. For research on stars, however, mirror telescopes (mostly of the Newtonian type) were again customary owing to their great advocacy by Sir William Herschel (31, p. 539) and were in any case manu-



DESCRIPTION

DE LA

LUNETTE ACHROMATIQUE.

Faite avec des TUYAUX GLISSANTS de CUIVRE,

Par P. & J. DOLLOND, OPTICIENS,

DANS

Le Cimitiere de St. PAUL à LONDRES.

LA methode commune de faire les tuyaux glissans des Lunettes d'approche a été avec du papier couvert de velin ; mais comme on a trouvé ces tuyaux sujets à plusieurs inconvenients, à cause de l'humidité de l'air, on les fait à présent de cuivre très mince, et le tuyau exterieur de bois d'acajou, ou de cuivre. Comme elles sont très portatives, et comme on peut s'en servir avec promptitude, elles sont les plus commode pour les officiers de l'Armée, pour cette raison on les appelle *Lunettes Militaires*.

Les tuyaux glissans sont tous faits pour s'arreter quand tirés à leur propre longueur, de sorte qu'en mettant une main au tuyau exterieur A, fig. 1. et l'autre main au bout du plus petit tuyau B, la Lunette paroît, d'une *tire*, etre rendue à sa longueur, comme repréſentée par fig. 3 ; alors aucuns des tuyaux peuvent etre glissés un peu en regardant au travers, et l'objet rendu distinct à la vûe.

Afinque les tuyaux se glissent proprement, ils passent tous par des ressorts ou tuyaux courts, qui sont visibles à a, A, et c, fig. 2. Ces ressorts se dévident des bouts des tuyaux glissans par le moyen des bords dentelliés qui s'etendent, et les tuyaux peuvent etre ostés l'un de l'autre quand on le trouve necessaire.

Il y a quatre oculaires convexes à cette Lunette achromatique, dont les surfaces et les longueurs focales sont proportionnées de maniere à rendre le champ de vûe fort large. Ces oculaires font tous contenus dans le plus petit tuyau glissant ; on en peut voir trois en dévissant le tuyau à *e e e*, et le quatrieme, qui est au bout du tuyau, se trouve en dévissant le ressort à *c*.

Ces Lunettes sont de quatre longueurs et grandeurs differentes, communement appellés, 1 pied, 2 pieds, 3 pieds, et 4 pieds ; mais pour etre plus particulier, les dimensions, &c. sont données, comme suivantes :

Longueur quand en ufage.	*Longueur quand fer-mée.*	*L'ouverture de l'objectif achromat que.*	*L'ouvrir gradiſſant en e d'autre...*	*Prix.*
24 pouces.	5 pouces.	1, 1 pouces.	22 fois.	6 onces.
28 ditto.	9 ditto.	1, 6 ditto.	25 ditto.	16 ditto.
40 ditto.	10 ditto.	2, 0 ditto.	45 ditto.	30 ditto.
52 ditto.	14 ditto.	2, 75 ditto.	55 ditto.	64 ditto.

Fig. 3. French text (probably for continental circulation) of advertisement of Dollond's military telescopes, after the specimen in the Jena collection.

factured by a few skilled masters. That the making of large telescopes was included in the sphere of production of a few of the master opticians, is already made evident above in the case of W. Cary.

As far as concerns the spectacle trade, well-made and elegant articles were produced perhaps at a somewhat lower price than at the end of the 18th century (64). For spectacles for ordinary use silver (51) remained in preference for a still longer time.

Progressive master opticians were also not uninformed in theoretical optics (47), pp. 459–60) and highly estimated the value of their training. This conclusion can be supported by two different pieces of evidence, which we shall now consider. The spectacle manufacturers held to the ideal of an aid to vision having least possible spherical aberration for the direct ray-bundle and, therefore, considered

the so-called "crossed lens" certainly the best lens form. When in the year 1803 W. H. Wollaston (Fig. 4) ([47], p. 439), one of the chief furtherers of optical studies in the Royal Society of London, introduced his periscopic lens form which, as is known, ignored the avoidance of errors in the direct ray-bundle in order to attain a better ray-concentration in the oblique bundles, he received opposition from a London master optician, W. Jones, whose name is still preserved in our scientific literature. I will not enter here into all the details of this conflict, which grew

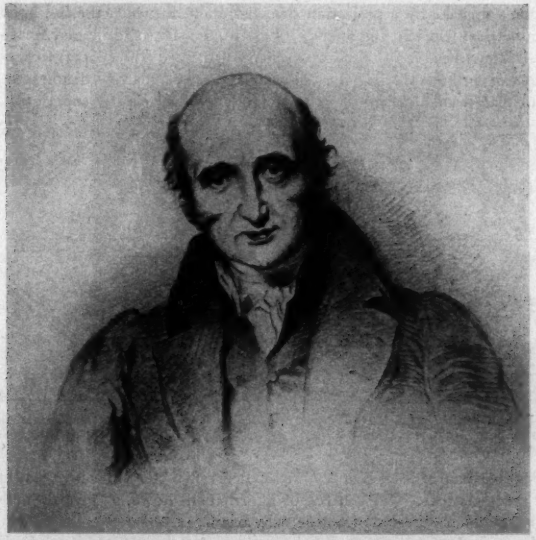


Fig. 4. William Hyde Wollaston (b. 6th Apr. 1766, d. 22nd Dec. 1828), after a portrait in the Science Library (reproduced by permission of the Librarian).

more bitter as it went on, as I have already, a few years ago, made it the subject of a fairly complete investigation [47]. A few results, however, are of importance. We now have no difference of opinion as to the mistake made by Jones—with many predecessors—that in the case of spectacles chief consideration should be given to the direct ray-bundles, but regard it incorrect fundamentally. When, however, he inferred that the Wollaston form of spectacle was no longer new, I should like to consider this objection more seriously than I did four years ago. In the meantime [56] I have had spectacle glasses come to hand which it is practically certain must date from the last years of the 18th century and the glasses

were menisci of strong refractivity $r_1 : r_2 = 1 : 2$ (Fig. 5). As we now know that such types were offered for sale in a small business in Munich, the possibility is not easy to deny that lenses with such deep curves were included under the older menisci not described in greater detail by Jones. The conflict, moreover, throws some light on the question whether Wollaston had at that time already consciously considered the rotation of the eye. I have made statements in favour of the contrary in a previous paper (41), and it seems to me now that his manner of opposing Jones confirms that previous assumption. For if Jones (47), p. 479) tried to prove Wollaston's mistake by a projection demonstration, in which the full aperture of the symmetrical lens and the meniscus was utilised, it would be easy for someone who well knew the rôle of the rotation point of the eye (47), p. 453) to show also, by means of an objective experiment with a relatively narrow diaphragm (about 1/10 in.) placed an inch away from the inner lens vertex, the superiority of the

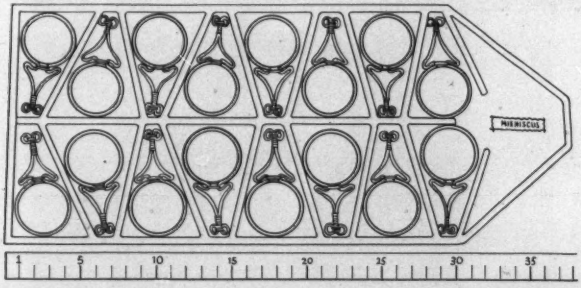


Fig. 5. Plan of a trial lens case (two lenses were deeply curved menisci); the stamped rims bear the inscription "Joann. Paul. Hirn in Munchen" (b. 1719 or 1720, d. 1799); after the specimen in the Jena collection.

meniscus that had pleased him so much when put to the subjective test of using it as a spectacle lens. Our sources of information, however, give us nothing to show that such an experiment was actually tried.

This conflict affords further important confirmation for the spreading of the knowledge of grinding, which according to Wollaston (47), p. 480) in the year 1812 was in the possession of all the London spectacle makers*. We shall be able to throw a little more light upon this from the record of a somewhat earlier period.

Fig. 6. Front view of Benjamin Franklin's bifocal spectacles, after his sketch of 23rd May 1785.

Here we must mention the bifocal glasses (Fig. 6). I have already mentioned (48) that they were probably first made about 1760 in London; but if one confines oneself to Benjamin Franklin's discovery in 1784, there is no doubt

* In the meantime I have learned of Mr Court's important discovery that the grinding of lenses on blocks was invented by Marshall between 1690 and 1693.

they were made in England. One may perhaps rely on the French importation patent of Biette(11) of 20th May, 1808, relating to bifocal spectacles, for I cannot assume that such articles would have been made at that time at a place other than London, although they may have had to make their way via an intermediate neutral place.

Before we come to study the London history of spectacles further, a glance must be made at the relation between the important medical men of the Royal Society who also had a knowledge of physics and the opticians. We are here concerned with

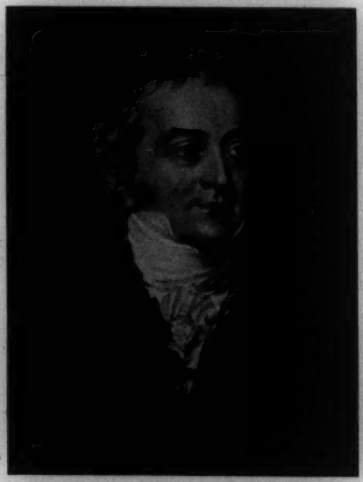


Fig. 7. Thomas Young (b. 13th June 1773, d. 10th May 1829), after the frontispiece in G. Peacock's "Life of Thomas Young," published in 1855.

C. W. Wells (b. 1757, d. 1817), W. H. Wollaston (b. 1766, d. 1828), and Thomas Young (b. 1773, d. 1829) (Fig. 7) who are respectively noted for their measurements of accommodation ((68), p. 107), the introduction of periscopic spectacle lenses(47), and the improvement of optometer measurements ((72), p. 35), the explanation of accommodation, the setting up of very important calculation formulae, and the numerical description of astigmatism of the eye. With the very considerable importance of the advances either attained or prepared for by the above investigators, one is grieved to record that at the time they had no appreciable influence upon the London master opticians. Whether they consciously, like Jones ((47), p. 449) in the cases of periscopic glasses, and unconsciously like J. Dollond ((47), p. 460) by shunning the deep curvatures necessary according to Wollaston's scheme, shut

themselves off from these advances, or whether these innovations were too far in advance of their time for the intelligence of the master spectacle-makers and their customers can hardly be decided now.

One act of the London master opticians must be mentioned here, and that is the invention and sale of monocles ([42], p. 38). They are known to us from a note of the year 1813, though they are not put forward there as a special novelty, so that it is probably correct to set their date—also according to other indirect testimony—back a few years further, perhaps to 1806 or 1807. I shall return to this presently.

Fig. 8. Pierre Louis Guinand (b. 20th Apr. 1748, d. 13th Feb. 1824), after a lithograph by Domon, representing him towards the end of his life.

The Relation between London and Viennese Optics: the Influence of Voigtländer

The great importance of the English achromatic telescope, which the firm of Dollond put upon the market from the year 1758, was recognised everywhere with intelligent admiration; we certainly know how the skilled Parisian court optician C. Passement ([43], p. 68) was able to present in 1761 an achromatic hand-telescope to the king, and how at about the same time the young P. L. Guinand (Fig. 8) of Neuchâtel first tried to manufacture industrially the flint glass necessary for such telescopes[28]. In the meantime the fame of the English telescopes and

spectacles had certainly not declined, and thus it came about that the young Viennese journeyman optician Johann Friedrich Voigtländer (Fig. 9) was introduced, during his years of travel for rational ideas, into the English works-experience ((66), p. 438). According to Fraunhofer, at that time a sound training in this field was not to be acquired in Germany.

We do not know exactly when this plan was realised, but it is certain that Voigtländer's stay in London was ended before the years 1807–8, as he became master craftsman in Vienna during this latter year. Under which master or masters

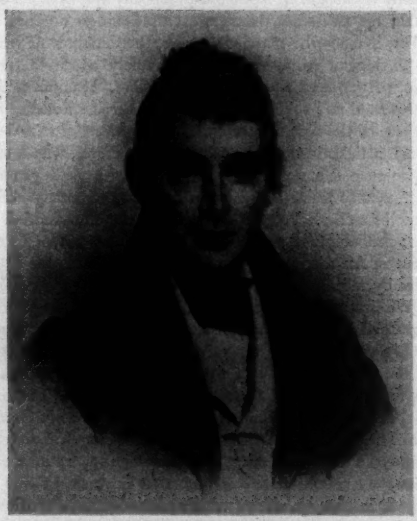


Fig. 9. Johann Friedrich Voigtländer (b. 21st May 1779, d. 28th Mar. 1859), after an engraving made by Kriehuber in 1832.

he worked in London is likewise unknown; I consider it not improbable that he worked for some time with the firm of Dollond as he later advertised the Wollaston periscopic spectacles in Vienna, mentioning the name of Wollaston as the inventor. This conclusion is probably justified, as, under the limited publicity of the English patent ((48), Ref. 68) of that day, knowledge of the protected article was not freely imparted to industrial workers. Apart from this we know merely from the tradition which has remained in Vienna that he was experienced in the grinding of a number of lenses on one tool at the same time. All the rest we must try to find out by inference and, as direct knowledge of him has gone altogether, that is the only

possibility of determining the bearing of this man upon the relations at that time between London and Vienna. We will now briefly deal with these inferences, as they are of not inconsiderable, though as yet mostly overlooked, importance for the English handicraft of that time.

The young journeyman may have travelled from England to the Continent during the year 1807, perhaps in a smuggler's vessel via Heligoland or by a neutral ship, for open traffic was impossible between England and the Central Europe under Napoleon's sway. We certainly know that he became a business optician in Vienna in 1808, obviously so departing from the practically purely mechanical business of his father that his two elder brothers set up business on their own account. Somewhat earlier, in 1807, he married Amalie, the daughter of his old Stuttgart teacher J. H. Tiedemann who, we can fairly safely conclude from a letter of Fraunhofer ((61), p. 53), died shortly after that time. It appears that the young business-man exported and sold carefully manufactured spectacles of the English type, probably one of the first master craftsmen in the German-speaking area to offer for sale such articles in a good quality. G. S. Plössl, who later, when independent, likewise reaped a noteworthy harvest in the good ground of English handicraft practice, was trained by him to become technically skilled in this as well as in other branches. Voigtländer delayed the introduction of periscopic spectacle lenses; probably the war period of 1808–14 was too disturbed, so that when he took out an Austrian protection for this invention in the summer of 1815, he was forestalled by an imitative production of the English specimen by A. Duncker in Rathenow. We first observe the English influence with the monocle mounted in a ring and grasped in the closing muscle of the eye ((66), pp. 439–40) which it is certain he sold probably under the same "Ringstecher" to a Dutch diplomat (Jonkheer van Boreel) at the time of the Vienna Congress, which sat from the autumn of 1814 to the spring of 1815. As to the proofs of this, I reconsidered them a short time ago, one not very reliable from the Count A. de la Garde and a more recent one from H. Rumbold. As correspondence between London and Vienna would be almost out of the question in the late winter 1813–14 for an unpretentious business optician, one would rather assume that he brought this novelty from London in 1807–8, in consequence of which one is led to an earlier invention, as from English printed accounts* we first hear of the new monocle in 1813. As already mentioned, he first ventured upon the introduction of periscopic spectacles in 1815, and one may further conclude ((59), p. 61) that the extraordinary fruitfulness of the Benediktbeurn undertaking may have somewhat disturbed his plans, as the superior quality of the productions directed by Fraunhofer perhaps prevented the appearance of his achromatic terrestrial telescopes on the market. The spectacle and theatre-glass trade remained open to him, however, as Fraunhofer ((61), p. 73) withdrew from it in 1817 or perhaps earlier.

* I mentioned a few years ago the little knowledge of the monocle which I have at first hand, namely in the advertisement of Jones, and printed in the text of the notice in the references. I think it is very probable that a systematic research in the treasured books of England would reveal still earlier information, for Voigtländer's sale in 1814–15, as far as we know the first sale of such an article, renders this almost conclusive.

Voigtländer's Double Opera-glass and Rimless Spectacles: the Influence of the Vienna Polytechnic Institute

The innovations traceable to J. F. Voigtländer(67) do, in fact, lie in these directions left open by Munich. He proved a worthy pupil of his London master and can hardly be said to have remained like the average English optician of that time. In 1823 he patented the combination of two achromatic theatre-glasses into a double opera-glass and thus produced a quite extraordinary and far-reaching impetus. Not as though the idea and production were at all new, for we learn of a double telescope made by J. Lipperhey back in the late autumn of 1608 ((45), p. 37) and achromatic twin-telescopes were proposed and described even in 1787 by L. Selva ((45), p. 39). That the new Vienna impetus reached so much farther, was due to the possibility which now existed of obtaining satisfactory small pieces of optical glass for such articles. In Paris J. P. Lemière in particular took up the Voigtländer idea and gave the mount(50) a form which is still in use for double opera-glasses (Fig. 10). If we consider that Fraunhofer in 1817 or before when

Fig. 10. An early form of a double opera-glass, according to the first part of J. P. Lemière's patent of 1825, after the specimen in the Jena collection; no maker's name given. The left-hand view shows the method of focussing by turning the *left* mother-of-pearl body.

engaged upon the Dutch telescope was confronted in Benediktbeurn with the difficulty of employing sufficiently skilled turners, i.e. turners who worked to his liking, we will recognise the enormous advantage which Paris, with its tasteful optical-mechanical handicraft trained in fine work, possessed, and long preserved in the case of field-glasses. Vienna, besides Paris, however, remained a long time a noted place for nicely made double opera-glasses, and these forms seem gradually to have been produced in other places as well, though perhaps hardly with such perfection.

A few years later, about 1825, though the actual year of their introduction is not known, the Viennese master succeeded in producing the first rimless spectacles (Fig. 11) although clumsy at first and principally for short-sighted persons(53). We only know of this through a later note of about the year 1840, though there is no reason to doubt the verity of this claim.

Fig. 11. A reconstruction of the probable form of J. F. Voigtländer's glass spectacles of 1824–25.

At about this time the influence of S. Stampfer, the optical expert from the Vienna Polytechnic Institute, may have first made itself felt(53) and it looks as if

for a time Voigtländer's workshops made particularly deeply curved glasses known as "extra periscopic." One may well assume in this respect that the leading spirit of this was Stampfer, who exerted a great influence upon the Viennese industry at this time. To the workshops of recognised standing there were added in the meantime (since 1823) those of G. S. Plössl who made himself independent, without, however, entering into any particularly sharp rivalry with his old master. It appears that he at first carried on microscope construction and under the influence of the microscopist J. v. Jacquin adopted French ideas.

When J. Fraunhofer died in the summer of 1826, the Vienna Polytechnic Institute successfully strove to introduce its Viennese pupils also into the terrestrial telescope trade, and this certainly occurred in the case of Voigtländer and Plössl. Stampfer ((59), p. 64) trained his opticians in the proper determination of refraction and dispersion and in the standard form of objective invented by the great Bavarian, while Prechtl ((59), p. 63) devoted his attention to improvements in production and testing. That the performance of at least these two workshops was increased, is supported by the testimony of the Göttingen mathematician Gauss ((66), p. 444), who, though considered an expert not easily satisfied, on this occasion gave a very favourable criticism. It would be incorrect, however, to regard these two Vienna masters only as imitators; under Stampfer's direction, Plössl ventured upon the manufacture of distance objectives (Dialyte), the last which resulted from the stimulus given by the English expert Rogers. Stampfer carefully worked out the matter theoretically, and Plössl was able to manufacture and dispose of these objectives in quite considerable dimensions.

It will already be seen from this short account that the small offshoot, which came from England and was planted by J. F. Voigtländer in Viennese soil, flourished under extraordinary favourable conditions and bore very gratifying fruit; but finer results were to follow later, as we shall shortly see.

London Craftsmen and Spectacles (Monocles, Single Eye-glasses, and Trifocal Glasses)

Returning to London, we do not exactly know how the periscope type of spectacles fared there. We can only report, from an earlier date, their friendly reception in Paris, where the capable optician R. A. Cauchoix (13) interested himself in them, and was the first to give attention to the mirror images which occasionally disturbed the wearer. The reception in the German-speaking area has been mentioned above, but we know little about the reception in England; the attitude of aversion is so strongly and distastefully represented by Jones in 1804 and 1813, that we may consider ourselves without any consistent and conclusive evidence. Here also (49) one may bear in mind the extraordinary self-conceit of the glass workers of London, of which a casual testimony is preserved from 1831; we find throughout a point of view similar to that of Jones, and may possibly be permitted to generalise or even explain from this, why in the middle of the third decade the English were so completely astonished when the Fraunhofer results became known.

Returning to the monocle, the origination of which may be set back, perhaps, to some time previous to the year 1807, its development is not satisfactorily known to me. The business advertisements of the firm of Jones Bros. date from 1813, and, as mentioned above, its appearance at the Vienna Congress is known from 1814–15. In addition a later account by R. Greeff ((27), p. 228) of a journey undertaken in 1819 contains a paragraph from which one must conclude that the monocle was then fairly commonly seen in the streets of London. In good agreement with this is the next mention that I know of, of date 1825, in the book on spectacles by W. Kitchiner ((34), p. 76) where he expresses himself highly in disfavour of this practice.

In Vienna we later find here and there humorous references ((51), p. 126) to their striking form, and then at a much later date young Charles Dickens, in his witty manner, ridicules in *Little Dorrit* the society custom which had evidently spread in the meantime (I am referring to young Clarence Barnacle). At about that time the monocle with handle (Fig. 12) certainly remained a prominent form of aid to vision; it is mentioned by Dickens, so far as I remember, both in *Pickwick Papers* and in *Little Dorrit*—in this case associated with the leaders of fashion, Mrs Gowan and Mrs Merdle*—and we have some fine specimens in Dunscombe's collection ((51), p. 123). Fitting in well with this is the fact of the existence of the handled spectacles of 1825, designed with great skill by Bretell Bate (9), which could be shut up so that they looked like a single hand-glass with handle, for use with one eye alone (Fig. 13). For the sake of completeness, the Brewster kaleidoscope (12), invented in 1817, must be mentioned. To its excellent design it owes its spread throughout the whole civilised world, and must not be left out of this account in spite of its simple construction—it makes use merely of plane mirrors.

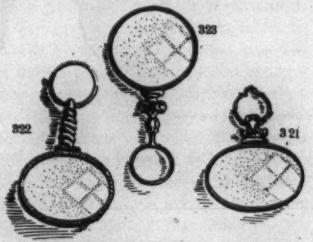


Fig. 12. Some gold eye-glasses with handles, from Mr Dunscombe's collection in the Science Museum.

Late in the year 1826 we obtain a clear, though not very gratifying, picture of the London spectacle trade from the detailed statement of a skilled mechanic called J. I. Hawkins (30) who at that time was interested in trifocal spectacles

* The events chronicled in *Little Dorrit*, which was published in 1855–56, were supposed to have taken place about 1826, but I am not sure whether that time has been reproduced with specially great care. Book I, Chap. x, "Containing the Whole Science of Government"—"...He had a superior eye-glass dangling round his neck, but unfortunately had such flat orbits to his eyes, and such limp little eyelids, that it would not stick in when he put it up, but kept tumbling out against his waistcoat buttons with a click that discomposed him very much." There is still more about the eye-glass in this chapter, and further cutting remarks against Clarence Barnacle are to be found towards the end of Chap. XVII, "Nobody's Rival." As to Mrs Merdle and her way of using her eye-help in looking at persons of lower rank, see Chap. XX, "Moving in Society."

(Fig. 14). Hawkins had been a maker of musical instruments and had worked for a long time in America, where he appears to have brought information about Franklin's invention of bifocal spectacles. As already mentioned, the English opticians appear to have looked with favour on the invention a considerable time earlier, but then they were not inclined to take it up, possibly because of the general feeling against American customs (see Dickens' *Pickwick Papers*,* Chapter XLV). In any case Hawkins seriously thought of having his trifocal spectacles made, but he found to his great disappointment that the London handworkers were very little inclined to consider his well thought out suggestions for the spectacle frame necessary for his trifocal lenses. It may be further mentioned that he made excellent

Fig. 13. Perspective view of R. Bretell Bate's double eye-glass, according to his patent of 1825.

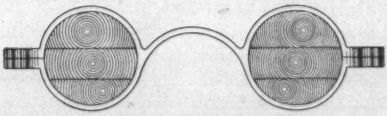


Fig. 14. Front view of J. I. Hawkins's trifocal spectacles, according to his paper finished in the Autumn of 1826.

use of Thomas Young's optometer and with its help found that he had slight astigmatism. He excelled the incorporated opticians in the determination of inter-ocular distances and has left behind him—in a sketch which must be completed to become suitable for the purpose—proof that he was not unfamiliar with the rotation point of the eye.

First Efforts to melt Optical Glass in England

If now we turn our attention to the position of the optical industry in London, so far as it is known to us from contemporary sources, it appears that the poor quality of glass was considered inevitable, especially as no helpful information

* *Pickwick Papers* was published in 1837, the events chronicled being supposed to have taken place about 1827. Chap. XLV—"... Have a passage ready taken for 'Merriker. The 'Merrikin gov'ment vill never give him up ven they finds as he's got money to spend, Sammy. Let the gov'ner stop there till Mrs Bardell's dead or Mr Dodson and Fogg's hung (which last event I think is the most likely to happen first, Sammy), and then let him come back and write a book about the 'Merrikins as'll pay all his expenses and more, if he blows 'em up enough."

came from France when friendly relations were renewed with that country. The appreciably greater development in Benediktbeurn and Munich was at first quite unnoticed in London. The lack of close relations between London and Munich is obvious from the fact that Fraunhofer's paper(22) published in the *Journal* of the Bavarian Academy, on the accurate determination of refractive indices with the aid of the dark lines in the sun's spectrum, was quite unknown in London. Even as late as 1821, Sir John Herschel(32), in his excellent paper on the computation of telescope objectives, makes no reference to the necessity of carefully determining refractive and dispersive constants. If I am correct in my interpretation of his letter of 1825 ((61), p. 111) he did not know Fraunhofer's method of measuring refractive indices until his visit to Munich some time after 1821*. Thus work was carried on to a certain extent in a routine manner and only telescopes of small diameter were made; our best authority with regard to this period is W. Kitchiner, to whom reference has already been made. He was somewhat eccentric, as H. H. Emsley(20) has recently shown, but he devoted his whole affection and attention to the telescope, both in the observation of distant terrestrial objects and in astronomical research. He mentions the names of opticians who worked for him, e.g. Berge, Dollond, Tulley, and gives parts of the price lists of the two last named. We find that, with one exception to be referred to shortly, no telescope of greater diameter than 5 in. (12·5 cm.) was offered for sale at that time in London. We have very good confirmation of this in a price list of the firm of Dollond which is quoted in a number of Schumacher's *Astronomische Nachrichten*. This price list also gives us a good idea of the kind of spectacles produced in London at that time.

In contrast with this rather dark and dull picture of the optical world we have the enthusiastic report Struve(65) made on the refractor which was completed by Fraunhofer in 1824 for Dorpat. It is noteworthy that D. Brewster, judging from his remarks(13) on this report, was not so much concerned with the development of the means for furthering astronomical investigations, as he was annoyed that such an excellent instrument should have been designed and manufactured in a foreign country.

Very probably the English savants and manufacturers ascribed the advantage possessed by Munich to the free provision of good glass by the Benediktbeurn factory and they immediately sought out a remedy. The committee, which included men such as Sir John Herschel, G. Dollond, and Michael Faraday, appointed by the Astronomical Society to investigate the question of glass, did what it could, but the death of P. L. Guinand on the 13th of February, 1824, spoiled the plans which had probably been made for getting him transferred to London. His relatives, namely, his widow Rosalie and younger son Aimé, do not seem to have been approached, so that the appreciable experience of the former was still available in French Switzerland. Attempts seem rather to have been made to manufacture glass in England, and for this purpose Faraday, a man of world renown and a zealous worker, was available. Faraday's great knowledge of chemistry was supple-

* Meanwhile I have been told by Dr Steavenson that Sir John Herschel went to Munich in 1824 and made Fraunhofer's acquaintance then.

mented by the experience of the Green and Pellatt glass-works, but, although the State (56) endeavoured to ensure success of the project by means of grants (apparently £6000) and tax exemption, we learn from a report (21) at the end of 1829 that no appreciable success had been attained, and the production of convenient raw material in England was not improved. P. L. Guinand's suggestions for the improvement of the production of optical glass (28) and in particular the simple stirrer he introduced early in 1805 were not known then, and the successful development at Benediktbeurn between 1809 and 1813 had not spread abroad. Large telescope objectives in England must either have been made from foreign glass or obtained entirely from abroad.

The first advance was made by the master optician C. Tulley (7) when Guinand, as the result of his correspondence with English scientists with regard to the improvement of glass manufacture, eventually produced a workable flint glass disc of a diameter which was remarkable when judged by English standards. Although the selection of the corresponding crown glass disc presented great difficulties—the first piece was found to be of no use as soon as it was ground—success was attained with the second piece and his persistence brought Tulley well-earned fame. The second advance was made by the well-known and esteemed wealthy amateur astronomer J. South (63). He was so pleased with the large French telescope objectives, which were apparently made from Swiss discs, that he bought and took home two of them. According to the reports to which I have had access, the State exempted him from the glass tax. These were the only two advances in England for at least some years. I shall have some further remarks to make about this later.

Airy's Work on Spectacles and his Theoretical Papers: their Influence on Craftsmen

Meanwhile the academical assistance rendered was by no means confined to the question of the production of glass; methods of computation were also investigated. The extraordinarily fortunate invention of sphero-cylindrical spectacles in 1825 by the young astronomer G. B. Airy (Fig. 15) should have given a lasting impetus to the spectacle trade in England, but evidently the time was not yet ripe. Airy's lecture on the subject was delivered in 1825, but was first published two years later (1).

We have already mentioned that in the years 1800–1 Thomas Young had described the astigmatism of the eye and had attempted to correct it by the use of spherical spectacles set at an angle. So far as I am aware, no one at that time worried about this aberration; in fact Young himself did not consider his proof as an important part of his lecture. The general silence on this subject was first broken by the appearance of a medical thesis about ten years later. E. F. Fischer, a Berlin mathematician, had for years* given to his pupils a demonstration of this aberration, which he considered fairly widespread, by means of two sets of

* If it is assumed that Gerson's academical course occupied four years, the demonstration must have been given at least four and a half years earlier. We may, therefore, conclude that Fischer demonstrated ocular astigmatism to his pupils about 1805 or 1806.

parallel straight lines at right angles to one another. One of his pupils, G. H. Gerson (24), considered this so important that he investigated it in his thesis for the doctorate in 1810. Even this did not arouse general interest. In a French patent (23) of 1813 dealing with solar power machines the suggestion was made to replace the ordinary axially symmetrical lenses by those with crossed cylindrical surfaces. This rather mediocre suggestion was in fact quite widely taken up and described; it was referred to in 1818 by Altmütter ((4), p. 412) of the Polytechnic

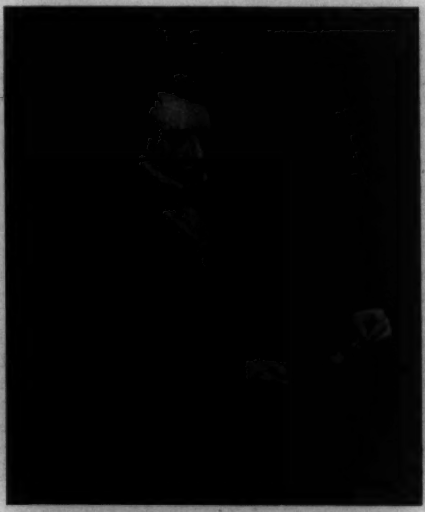


Fig. 15. Sir George Biddell Airy (b. 27th July, 1801, d. 4th Jan. 1892), after a portrait in the Science Library (reproduced by permission of the Librarian). The photograph may have been taken in the fifties.

Institute in Vienna, and in Edinburgh D. Brewster* ((14), pp. 50–51) had such lenses made and reported on their performance. From later remarks of Airy it is known that a vague report of this French invention had also reached Cambridge in 1825 and had caused amazement there.

In 1825 Airy, one of whose eyes was affected with quite strong astigmatism and was nearly unusable, carried out his classical investigation of the power of the sphero-cylindrical spectacle glass, which the Ipswich optician Fuller made for

* I have so far not been able to find out the time of these experiments, but I should think it probable that they were made before 1818.

him. The idea, however, was too new and it was some time before enterprising opticians, both in England and America, endeavoured more frequently to relieve the troubles of astigmatic patients in this way. I have given the bibliography relating to this subject elsewhere (54) and information about previously known applications in another paper (46). In conclusion, reference may be made to a remark of an anonymous writer (5) to the effect that in 1828 John McAllister of Philadelphia made "concave cylindrical lenses" for C. E. Goodrich. This proves the rapid spread of the knowledge of Airy's work, and shows McAllister to have been a well-instructed optician.

Meanwhile, Airy did not confine his attention to this problem, which had arisen from his defective eyesight; shortly afterwards he published two theoretical papers dealing with the approximate computation of the aberrations of oblique pencils. Probably the theory of the telescope eyepiece (2) interested him primarily, but in the second appendix (2) he devoted his attention to spectacles and the camera obscura lens, which, in agreement with Wollaston, he considered as their inversion; we shall have occasion to consider this more closely later. His pupil, H. Coddington (16), developed Airy's ideas from 1829 onwards and published the formulae for the computation of astigmatic pencils along principal rays of finite obliquity. These formulae are in a form which more closely resembles the modern formulae than those which had been published by Young nearly thirty years earlier. No one will doubt the high scientific value of this work carried out at Cambridge, but it seems to me that its importance to the practical optician is not so great as that of the work of the Viennese school, whose simpler methods, published at the same time, were put into daily practice under the direct supervision of those who had developed the methods. Thus it appears that the optical school in Vienna, which had been nurtured on English methods, made more rapid progress in the first third of the 19th century than the originators of these methods. In this connection it may be mentioned that the distance lens (Dialyte), which at this time was constructed to P. Barlow's design (8) by the firm of Dollond, was not nearly so successfully developed as the one designed by Rogers and made by Plössl under Stampfer's direction.

Successful Manufacture of Camera Obscuras, Microscopes, and Spectacles

In contrast with the unsuccessful production of telescope objectives in London at that time, good business was carried out with the Wollaston lens (Fig. 16) as an aid to sketching with the help of the camera obscura. I have recorded (57) what I know of the development of this instrument also in the 18th century. It can indeed be asserted that Wollaston's improvement, in spite of Jones's objections, actually was adopted; in France also this improvement was adopted and G. B. Airy, as we saw, gave a theoretical explanation of it somewhat later. There must have been a considerable demand for this instrument, for the new photographic and photochemical experiments carried out in France by Niepce and Daguerre and in England by H. F. Talbot were due to the desire to obtain by chemical means

permanent records of the attractive pictures projected on the image plane. In this connection the reference which is most familiar to me is to be found in Goethe's "Wahlverwandtschaften" (25) of 1812 where a description is given of an English traveller who showed to his friends on the Continent some particularly fine landscapes made with the aid of a camera obscura. Thus Wollaston quite unconsciously paved the way for the wonderful development of photography in England.

Only a brief reference can be made here to a purely theoretical performance of very great value, namely, Hamilton's work on the theory of ray systems (29). As in more recent times A. Gullstrand has developed the subject further and as we may hope that Mr T. Smith will give us further applications to quite modern optical problems, we shall by no means forget the value of this brilliant work. In the third and fourth decades of the 19th century, however, the work appears to have had no effect.

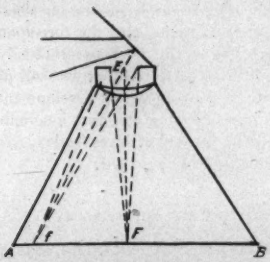


Fig. 16. W. H. Wollaston's camera obscura with periscopic lens and stop in front, after his paper of 1812.

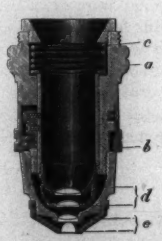


Fig. 17. Andrew Ross's microscope objective correction collar (modified), as made in Jena before 1893.

English opticians were also occupied with the improvement of the microscope. Lister's methods in the fourth decade furnished an impetus, and on account of the small diameter of the lenses required for this instrument the difficulty in obtaining raw material did not matter. In passing, reference may be made to the simple microscopes made by Goring and Pritchard (26) from precious stones. Although these perhaps represent a retrograde step, they testify to the skill of their producers. In any case we must mention the mirror microscope—nowadays almost forgotten—various designs of which Tulley (26) offered for sale. Unfortunately the managers of this firm, which we know to have existed from 1823, died within a short time of each other, and this may have assisted the young optician Andrew Ross, who was a pupil of Gilbert. Ross started business in 1837 and soon became known on account of his extremely ingenious design of the correction collar for microscope objectives (Fig. 17).

In the spectacle industry mention should be made of the comprehensive patent specification of G. R. Elkington (19) who in 1834 endeavoured to extend the scope of bifocal lenses by making the portion for near work also approximately normal

to the principal visual axis. Although this excited considerable interest and led to various suggestions for improvement, it apparently did not hold the field for long. Only one form of Elkington's pantoscopic spectacles remained and that not a very correct form (Fig. 18). They consisted of approximately semi-circular lenses for presbyopes, but they should, of course, have been normal to the principal visual axis through the near portion. Although this condition, which was of importance in connection with the invention, was not fulfilled, the old name was still retained. The greatest change with regard to eye-glasses took place at this time, namely, the end of the fourth decade, originating probably in France, where the pince-nez were developed after many fruitless attempts, and the corresponding English form—the "double eye-glass" referred to by Dickens—gradually but surely went out of fashion. Unfortunately it is to be feared that we shall not be able to obtain any more detailed records of this very important development, for Rouyer (60), who has left the only available information, is not very intelligible or informed on this point. What still can be done by way of investigation, namely, the systematic examination of journals, should not be neglected.

Fig. 18. G. R. Elkington's pantoscopic spectacles for presbyopic emmetropes, after his specification of 1834. The plane of the rings must be inclined at nearly 45° to the vertical.

The New Inventions of Stereoscopy and Photography

We come now to a very fruitful period in the history of optics. This, so to speak, was ushered in by the wonderful invention in 1838 by C. Wheatstone (Fig. 19) of the stereoscope (69), the fundamental principles of which he had designed in 1833. Although we know that about 300 B.C. the Greeks were familiar with some phenomena of binocular vision ((45), p. 18) and that from 100 B.C. attempts were made to produce striking experiments on binocular depth of vision by means of concave mirrors, these attempts being zealously repeated since the 16th century, no one had been successful in explaining these astonishing phenomena. In his first lecture in 1838 Wheatstone solved the problem with the aid of such clear and simple considerations that his demonstration, combined with the improvement (Fig. 20) described in January, 1851 (69), will always be looked upon as a classical piece of work. The sensation caused in the scientific world was great, although photography, which nowadays is inseparably associated in our minds with the use of the stereoscope, was not invented, and the pair of pictures could only be obtained at that time by the slow and inaccurate method of drawing. Wheatstone's ideas were spread abroad by means of translations in the French and German public press, but his scientifically designed, though rather cumbrous, instruments were not taken up to any great extent by the optical shops. We learn from contemporary sources ((45), p. 45) that only one shopkeeper in London, called Newman, had the Wheatstone instrument for sale.

In January 1839 the attention of optical circles was directed to an invention of still greater importance. At a meeting of the Academy of Science in Paris, Arago (6) announced that two Frenchmen, N. Niepce and L. J. M. Daguerre, had solved the problem of making permanent by chemical means pictures formed in the camera obscura. A short time later information came from London that an English inventor, H. F. Talbot, had also solved the problem in another way. It was soon realised that these inventions might enable portraits to be made which were true to nature and at the same time cheap. For this purpose a lens combination

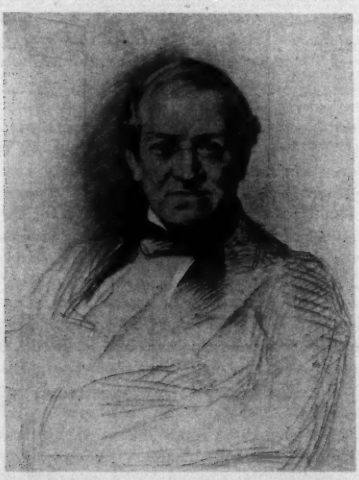


Fig. 19. Sir Charles Wheatstone (b. Feb. 1802, d. 19th Oct. 1875), after a chalk drawing in the National Portrait Gallery (reproduced by permission of the authorities).

possessing great relative aperture and a sufficient field of view was lacking, and many talented opticians made every endeavour to invent such a lens, which was sure of a wide sale. Of these we may mention ((66), pp. 446–7), C. Chevalier in Paris, Andrew Ross in London, T. Davidson in Edinburgh, and A. S. Wolcott, who was apparently a particularly skilled mechanic, in New York. The problem was not quite a new one, for even in the fourth decade of the century an English inventor, Miles Madder (35), had endeavoured to produce a projecting lens, later called an "opaque lantern," with great relative aperture, but he did not meet with success. The same result followed in the present case, for the lenses designed by the various inventors could only partially meet the need; they are sufficiently well known nowadays for us to judge of their unsuitability for the special purpose in

view. The much sought after prize fell to the lot of the firm of Johann Friedrich Voigtländer of Vienna who had received his training in England. We shall have more to say about this later.

Petzval's Help to Viennese Opticians

Austria had sent the Viennese professor A. v. Ettingshausen ((59), p. 65) to Paris upon a formal publication of Daguerréotype, and the delegate, while with

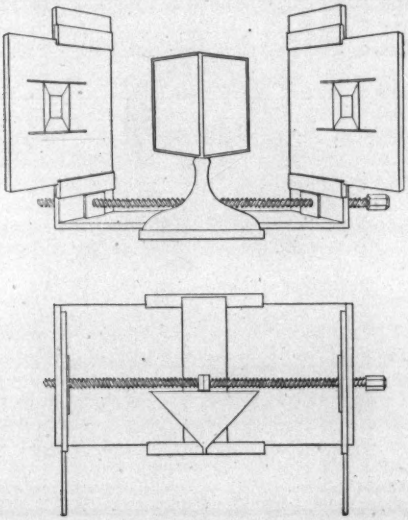


Fig. 20. C. Wheatstone's first published drawing of his mirror stereoscope (1838). Top—perspective view; bottom—plan.

the Paris experts, was made conversant with the special optical problems which were occupying their attention at that time. On his return home, he imparted his knowledge to the young professor of mathematics, Joseph Petzval, and induced him to seek after a solution, which, if successful, was, of course, to be made known to the Viennese opticians. It was the Viennese tradition to help the home opticians, and so he commenced the task. He worked, as we should say nowadays, in Coddington's manner with preliminary formulae, which he worked out with great completeness, but did not publish. The completion in the summer of 1840 of Petzval's calculations by W. F. Voigtländer, the only son of the English-trained

master, led, amongst other results, to the portrait lens which was soon to make triumphal progress throughout the whole photographic world. For some incomprehensible reason, the Vienna firm failed to take out even the slightest protection in foreign countries, so that there was thus not the slightest hindrance against a general imitation, which immediately commenced in all places where any sort of optical factory existed. In London, the works of A. Ross in particular took up this matter, and as conditions then existed, the needs of practical photography were for half a generation fully covered by the new portrait lens and the landscape lens developed from Wollaston's meniscus lens. So much was this the case that the ingenious arrangements presented for protection before the Patent Office, London, in September 1843 by the talented American, A. S. Wolcott (70), were forgotten after the early death of their inventor, although they comprised some very important forms, such as the symmetrical arrangement for rendering plane images. Whilst in most countries where photography was practised the portrait photograph obtainable by professionals and without much scientific knowledge was by far the most common, there early arose in England intelligent amateurs who were probably familiar with the camera obscura for drawing, and through whom the photographic camera itself was developed. These people who utilised the new technical skill desired a rendering which was true to nature and had to fulfil the condition (mainly depending on sufficiency of focal length) that the photographer could also correctly view the plate produced. In the photographic process, however, the lens used for taking the photograph was, as it were, "independent," and might give an image, which although correct in itself, was on so small a scale that it gave an impression of incorrectness to the average person inspecting it. These difficulties were recognised by English amateurs like G. S. Cundell (17) and described in journals dealing with physics—as a technical photographic press was non-existent till years afterwards.

Very gradually correct views of the achromatisation desirable for photographic lenses developed, and it may be recorded as a result due to the London opticians during this period (39), p. 104) that towards the end of the fifth decade (1849) A. Ross, in a zealous collaboration with A. Claudet, who had come over from France, gave photographic achromatism to the Petzval portrait lens.

In 1846 Airy (3) again took up the measurements of the astigmatism of his own eye, with which he had so brilliantly commenced his career as spectacle-theorist twenty-one years previously. This work did not escape a spectator so observant as F. C. Donders, but as a whole there again seems to have been only a small influence upon eye specialists and opticians.

The Development of Successful Glass Works on the Continent and in England

At the close of this survey we may take a glance at the establishment in this country of the art of manufacturing optical glass which came about in the year 1848. It was previously pointed out that the experiment conducted by Faraday, of manu-

facturing optical glass in England commercially, was not continued after 1829. Optical glass was ordered, when necessary, from abroad; the experienced optician W. Simms (62) had, however, at the end of this period quite plainly set out the difficulties to be overcome in this direction, and gave them as the principal cause of the set-back of the London optical industry. Abroad, there were now four main foundries, which were all more or less related to the Benediktbeurn works, where, in the years 1809–13, the combined labours of P. L. Guinand and J. Fraunhofer became the basis of the commercial production of satisfactorily homogeneous glass. The old Benediktbeurn foundry was out of the question for London, as it was carried on for the Munich management (i.e. its proprietors) alone. On the contrary, P. L. Guinand started in 1816 ((28), p. 194) a foundry in Les Brenets in the Canton of Neuchâtel, which, after 1818, was carried on principally for the export to France, and as remarked above, was after 1824 managed chiefly by his wife Rosalie and his second son Aimé. As in time the business developed, Henri Guinand, the eldest son, previously a clockmaker in France, entered into the practice of glass manufacture, and, as discord reigned in the Guinand family, tried his luck in Paris, where he collaborated in 1827–8 with a skilled expert, G. Bontemps, and made the latter familiar with the stirring process. This union dissolved also, and in the French-speaking area three works existed during the fourth decade: the West Swiss one managed by Guinand's widow and the reliable apothecary T. Daguet (33), the Paris one of H. Guinand and his son-in-law Feil, and lastly that conducted by G. Bontemps in Choisy-le-Roy. Of the two French firms that of Guinand-Feil was probably the more efficient, but that of G. Bontemps is also of recognised merit. As now the gradual development of the Dutch double telescope (40), and, subsequently to 1840, the photographic objective, increased the market for pieces of glass of a medium size, these two French works attracted as customers practically the whole of the world's optical works, and transformed the production of optical glass into a profitable concern.

The English glass-industry was now favoured by an enormous piece of good fortune, in that G. Bontemps, owing to political trouble, in 1848 left his native country, and found shelter in Chance's glass-works at Birmingham, with the resulting formation in England of an efficient optical glass-works, which at once entered into the small group of efficient foundries.

I will close my address at this point and omit mentioning the historical development of the stereoscope, the binocular microscope, and the microscope objective and, in particular, the extraordinarily fruitful work on the development of the photographic wide-angle lens and of the viewing lens, as these first come into consideration during the second half of the 19th century and so are not included under the present title.

In conclusion I must express my hearty thanks to a great number of helpers. The translation has been kindly carried out by Drs John S. Anderson and A. F. A. Young, some of the lantern slides have been prepared by Mr Banfield of the Imperial College of Science, and the blocks of Figs. 2, 5, 6, 8, 14, 17, and 20 have been lent by Messrs Julius Springer of Berlin. During my stay in London I have

had such effective help from librarians and others that I can only acknowledge it with the deepest gratitude. I must especially mention the Chief Librarian, Mr A. A. Gomme, and Mr W. E. White of the Patent Office Library, the Librarians of the Royal College of Physicians and of our Society, Mr D. Baxandall, Dr R. S. Clay, and Mr T. H. Court. Without their generous help many of my remarks could either not have been made or not with the desirable accuracy.

SOURCES AND REFERENCES

(1) Airy, G. B. Ref. (2) in (18); see also the collection of translations (54). [132.]*
(2) —— Ref. (14) in (58). [134.]
(3) —— "On a change in the state of an eye affected with a mal-formation." *Camb. Phil. Trans.* **8**, Part III 1846 (361–2). [139.]
(4) Altmütter, O. G. J. See under Rohr, M. v. Ref. (18) in (46). [133.]
(5) Anon. "Historical sketch of famous optical house in Philadelphia." *The Opt. Journ. and Rev.* **58** 1926 (31–2). [134.]
(6) Arago, D. F. J. "Le daguerréotype." *Comp. rend.* **9** 1839 (250–67). [137.]
(7) Astronomical Society. "Report of the Committee appointed by the council of the Astronomical Society for the purpose of examining the telescope constructed by Mr Tulley, by order of the council." *Phil. Mag.* **67** 1826 (377–82, 791–2). See also the French translation (not complete), *Bibl. Univ.* (*Sciences et Arts*) **32** 1826 (245–51). [132.]
(8) Barlow, P. "An account of a series of experiments made with a view to the construction of an achromatic telescope with a fluid concave lens, instead of the usual lens of flint glass." *Phil. Trans.* **1** 1828 (105–12), 1 fig.; see also *ibid.* **1** 1829 (33–46), **1** 1831 (9–15), **1** 1833 (1–13). [134.]
(9) Bate, Bretell. See under Rohr, M. v. Ref. (45) in (46). [129.]
(10) Baxandall, D. Ref. (2) in (52); see also the review of the original paper, *Centr. Ztg. f. Opt. u. Mech.* **45** 1924 (66, 68). [118.]
(11) Biette. Ref. (1) in (46). [123.]
(12) Brewster, D. "New optical instrument called the kaleidoscope for exhibiting and creating beautiful forms and patterns of great use in all the ornamental arts." *Brit. Pat.* 4136, 27th Aug. 1817. See also "A treatise on the kaleidoscope." Pp. viii + 166; 7 Plates. (Edinburgh: Arch. Constable & Co., L. Longman, Hurst, Rees, Orme, & Brown; London: Hurst, Robinson & Co., 1819.) [129.]
(13) —— "Further account of the large achromatic refracting telescope of Fraunhofer in the Observatory of Dorpat." *Edin. Journ. Science*, **5** 1826 (105–10). "Such is the description of Fraunhofer's telescope given by Professor Struve; and we think that no Englishman can read it without feelings of the most poignant regret, that *England has now lost her supremacy in the manufacture of achromatic telescopes*, and the government one of the sources of its revenue. In a few years she will also lose *her superiority in the manufacture of the great divided instruments for fixed observatories*. When these sources of occupation for scientific talent decline, the scientific character of the country must fall along with them, and the British government will deplore, when it is too late, her total inattendance to the scientific establishment of the Empire. When a great nation ceases to triumph in her arts, it is no unreasonable apprehension that she may cease also to triumph by her arms" (Brewster's remarks); "Report on double stars from a review of the starry heavens made with the great achromatic telescope of Fraunhofer," by F. G. [W.] Struve, *ibid.* **9** 1828 (79). [131.]
(14) —— See (54), pp. 50–51. [133.]

* The numbers in square brackets refer to the pages of the text where the sources and references are mentioned.

(15) CAUCHOIX, R. A. Ref. (1) in (46). [128.]
(16) CODDINGTON, H. Ref. (15) in (58). [134.]
(17) CUNDELL, G. S. Refs. (1), (2) in (39). [139.]
(18) CZAPSKI-EPPENSTEIN. "Grundzüge der Theorie der optischen Instrumente nach Abbe." (Leipzig: J. A. Barth, 1924.) Refs. (1), (22), (26), (29), (32), (40).
(19) ELKINGTON, G. R. Ref. (1) in (46). [135.]
(20) EMSLEY, H. H. "Optics and Cookery." *Optician*, **70** 1925–6 (173–4). [131.]
(21) FARADAY, M. The Bakerian Lecture "On the manufacture of glass for optical purposes." *Phil. Trans.* **1** 1830 (1–57), 2 + 7 figs.; German translation (somewhat abridged). *Pogg. Ann.* **18** 1830 (515–78), 9 figs. on Plate VIII; French translation, *Ann. Chim. et Phys.* **45** 1830 (85–100, 158–90, 225–70), 9 figs. on Plate I. [132.]
(22) FRAUNHOFER, J. Ref. (2) in (18). [131.]
(23) GALLAND, P. et CHAMBLANT, M. N. J. Ref. (1) in (46). [133.]
(24) GERSON, G. H. Ref. (1) in (46). [133.]
(25) GOETHE, J. W. "Wahlverwandtschaften." "Novels and Tales by Göethe. Elective Affinities; the sorrows of Werther; German Emigrants; the Good Women; and a Nouvelette, translated chiefly by R. D. Boylan, Esq." (London: H. G. Bohn, 1854.) Part II, Chap. x, p. 186. (About the Earl on a visit.) "At the hours which the ladies usually spent alone he was never in the way, for he occupied the greatest part of the day in catching such views in the park as would make good paintings in a portable camera obscura, and drawing from them, in order to secure some desirable fruits from his travels for himself and others. For many years past he had been in the habit of doing this in all remarkable places which he visited and had provided himself by it with a most charming and interesting collection. He showed the ladies a large portfolio which he had brought with him, and entertained them with the pictures and with descriptions. And it was a real delight to them, here in their solitude, to travel so pleasantly over the world, and see sweep past them, shores and heavens, mountains, lakes, and rivers, cities, castles, and a hundred other localities which have a name in history." [135.]
(26) GORING, G. R. and PRITCHARD, A. Ref. (3) in (18). [135.]
(27) GREEFF, R. "Lehrbuch der Formen und Fassungen der Augengläser und ihrer Verwendung in der Praxis." (Jena: Staatliche Optikerschule, 1925.) [129.]
(28) GUINAND, P. L. Ref. (5) in (58). [124, 132, 140.]
(29) HAMILTON, W. R. Refs. (1) to (4) in (18). [135.]
(30) HAWKINS, J. I. Ref. (1) in (46). See also the complete translation, *Centr. Ztg. f. Opt. u. Mech.* **43** 1922 (237–9, 256–9), 5 figs. [129.]
(31) HERSCHEL, Sir W. Ref. (7) in (58). [120.]
(32) HERSCHEL, Sir J. Ref. (1) in (18). [131.]
(33) KELLER-ZSCHOKKE, J. V. See M. v. Rohr's review of his works, *Z. f. Instrk.* **46** 1926 (598–600). [140.]
(34) KITCHINER, W. Ref. (1) in (46). [129.]
(35) MADDER, M. "Endless Magic Lamp." *Mech. Mag.* **17** 1832 (18), 3 figs. See also the report "Ueber eine neue Zauberlaterne." *Dingler's polyt. Journ.* **45** 1832 (58), 2 figs. [137.]
(36) PAYEN. "Rapport sur le concours relatif à la fabrication du flintglass et du crown-glass." *Bull. Soc. d'Encour.* **38** 1839 (470–3). [132.]
(37) PROSSER, R. B. Ref. (52) in (48). [118.]
(38) REPSOLD, J. A. "Zur Geschichte der astronomischen Messwerkzeuge von Purbach bis Reichenbach, 1450 bis 1830." (Leipzig: W. Engelmann, 1908.) [119.]
(39) ROHR, M. v. "Theorie und Geschichte des photographischen Objectivs." Ref. (17). (Berlin: J. Springer, 1899.) [139.]
(40) —— Ref. (18) in (18). This fact was here for the first time introduced as an explanation of the remarkable development of the Guinand-Feil establishment from 1846 onwards. [140.]
(41) —— "Das Auftreten des Augendrehpunkts in der Physiologie und in der technischen Optik." *Z. f. Instrk.* **35** 1915 (197–215), 11 figs. [122.]

(42) ROHR, M. v. Ref. (33) in (46). [124.]
(43) —— "Zur Entwicklung des holländischen Fernrohrs." *Z. f. Instrk.* **37** 1917 (65–70, 85–91), 4 figs. [119, 124.]
(44) —— Ref. (17) in (48), p. 2. See also the latest contribution to the subject, "Ueber Brillenpreise aus älterer Zeit." *Centr. Ztg. f. Opt. u. Mech.* **46** 1925 (184–6). [119.]
(45) —— "Die binokularen Instrumente." 2 Aufl. Refs. (67), (69). (Berlin: J. Springer, 1920.) [127, 136.]
(46) —— "Die Brille als optisches Instrument." Refs. (4), (9), (11), (15), (19), (23), (24), (30), (34), (42), (60), (72). (Berlin: J. Springer, 1921.) [134.]
(47) —— "Der grosse Streit bei der Einführung der periskopischen Brillengläser." *Centr. Ztg. f. Opt. u. Mech.* **43** 1922 (439–41, 449–53, 459–62, 468–71, 478–80, 488–91), 13 figs. [120, 121, 122, 123.]
(48) —— The Thomas Young Oration: "Contributions to the history of the spectacle trade from the earliest times to Thomas Young's appearance." *Trans. Opt. Soc.* **25** 1923–4 (41–71), 14 figs. Refs. (37), (44), (64). See also the German translation of the text (without sources and references) and a German version of B. Conrad's letter of 17th July, 1658, *Centr. Ztg. f. Opt. u. Mech.* **45** 1924 (194–8, 213–15, 225–6, 238–40), 14 figs. [118, 122, 125.]
(49) —— "Ein weiterer Beitrag zur Geschichte der Brillenherstellung." *Z. f. ophth. Opt.* **12** 1924 (26). [128.]
(50) —— "Zur Anlage der Jenaer Optischen Sammlung," 3 Mitt. *Deut. Opt. Wochenschr.* **10** 1924 (251–2), 3 figs. [127.]
(51) —— "Ein neuer Beitrag zur Geschichte der Brillenherstellung." *Z. f. ophth. Opt.* **12** 1924 (120–7), 8 figs. [120, 129.]
(52) —— "Additions to our knowledge of old spectacles: a summary of papers published in 1923–24 relating to the subject of the Thomas Young Oration of 1923." *Trans. Opt. Soc.* **26** 1924–5 (175–87), 9 figs. Ref. (10).
(53) —— "Wiener Brillen aus der Biedermeierzeit." *Z. f. ophth. Opt.* **13** 1925 (38–41). [127.]
(54) —— "Ueber ältere Arbeiten zur Feststellung des Augenastigmatismus." *Z. f. ophth. Opt.* **13** 1925 (42–51, 111–15), 6 figs. [134.]
(55) —— "Zur Entwicklung des ausziehbaren Handfernrohrs." *Z. f. Instrk.* **45** 1925 (378–83), 2 figs. [119.]
(56) —— "Zur Geschichte des Brillenkastens." *Z. f. ophth. Opt.* **13** 1925 (107–10), 1 fig. [121.]
(57) —— "Zur Entwicklung der dunklen Kammer (camera obscura)." *Centr. Ztg. f. Opt. u. Mech.* **46** 1925 (233–5, 255–7, 272–3, 286–8, 303–4), 10 figs. Also reprinted for Harting's "Sammlung optischer Aufsätze," Nr. 6, pp. 24, 8vo; 10 figs. [134.]
(58) —— "Fraunhofer's work and its present-day significance." *Trans. Opt. Soc.* **27** 1925–6 (277–92), 16 figs. Also Refs. (2), (16), (28), (31), (61), (66). [120.]
(59) —— "Zur Stellung des vormärzlichen Wien in der Entwicklung der gemeindeutschen Feinoptik." *Phot. Korr.* **62** 1926 (57–67). [126, 128, 138.]
(60) ROUYER, J. Ref. (1) in (46). [136.]
(61) SEITZ, A. Ref. (10) in (58). [126, 131.]
(62) SIMMS, W. "On the manufacture of optical glass in England." *Monthly Notices R.A.S.* **9** 1849 (147–8). See also the German translation, *Die Naturwissenschaften* **11** 1923 (160–1). [140.]
(63) SOUTH, J. "Two large French achromatic object-glasses purchased by Mr South," by D. Brewster, *Edin. Journ. Science*, 2nd ser. **2** 1829–30 (181). See also *Dingler's polyt. Journ.* **36** 1830 (171–2). Brewster's article concludes with the following passage: "Mr South paid a just tribute of respect to our government (and particularly to the Duke of Wellington), who afforded him every facility for bringing these object-glasses into the country, not only free from examination at the Custom House, but also free from all duty." [132.]
(64) SPIEGELHALTER, E. K. Ref. (66) in (48). [119, 120.]
(65) STRUVE, [F. G.] W. "Nachricht von einer auf der Dorpater Sternwarte angefangenen

neuen Durchmusterung des Himmels in Bezug auf die Doppelsterne." *Astr. Nachr.* **4** 1825–6 (61–4, 65–71). [131.]

(66) VOIGTLÄNDER, J. F. Ref. (6) in (58). [125, 126, 128, 137.]

(67) —— Ref. (1) in (45). [127.]

(68) WELLS, W. C. "An essay upon single vision with two eyes: together with experiments and observations on several other subjects in optics." (London: T. Cadell, 1792.) See also the German translation, *Z. f. ophth. Opt.* **10** 1922 (13–25, 38–46, 68–80, 97–114.) [123.]

(69) WHEATSTONE, C. Refs. (1), (3) in (45). When I looked up Wheatstone's quotation at the beginning of his second paper on the stereoscope (1851), I was delighted to find such a full description of the principal idea of the stereoscope in 1833. It seems to me that this evidence is of the highest importance in the Brewster-Wheatstone controversy with regard to the priority of invention. I shall therefore indicate here the source and give the quotation in full: Mayo, Herbert, "Outlines of Human Physiology," 3rd ed. Pp. xvi + 478, large 8vo. (London: Burgess and Hill, 1833.) "The convergence of the optic axes has to do in a certain degree with our appreciation of distance and real magnitude. When, indeed, objects are placed at such a distance that in regarding them the optic axes remain parallel, our notions upon these points are entirely derived in the ways already explained. But when they are situated nearer, the sensation attending each degree of inclination of the optic axes enters as an important element into our estimate. Mr Wheatstone has shown in a paper he is about to publish, that if by artificial means the usual relations between the degree of inclination of the optic axes and the visual angle which the object subtends on the retina be disturbed, some extraordinary illusions may be produced. Thus the magnitude of the image remaining constant on the retina, its apparent size and distance may be made to vary with every alteration of the angular inclination of the optic axes. The author also proves, that the adaptation of the eye to distinct vision exercises no modifying influence on these perceptions; and contrary to the opinions of Dr Wells and other eminent optical writers, that there exists no necessary connection between this adaptation and the convergence of the axes.

"One of the most remarkable results of Mr Wheatstone's investigations respecting binocular vision is the following. A solid object being placed so as to be regarded by both eyes, projects a different perspective figure on each retina; now if these two perspectives be accurately copied on paper, and presented one to each eye so as to fall on corresponding parts, the original solid figure will be apparently reproduced in such a manner that no effort of the imagination can make it appear as a representation on a plane surface. This and numerous other experiments explain the cause of the inadequacy of painting to represent the relief of objects, and indicate a means of representing external nature with more truth and fidelity than have yet been obtained. It would require too much space to enter upon the physiological views to which these experiments have led their author" (pp. 287–8). [136.]

(70) WOLCOTT, A. S. and JOHNSON, J. "Improvements in photography, and in the application of the same to the arts." *Brit. Pat.* 9672 of 13th September 1843. See also the discussion "Beiträge zur photographischen Optik aus dem Anfängen der Photographie." *Z. f. Instrk.* **39** 1909 (138–43), 3 figs. [139.]

(71) WORRIS, W. "An improvement in the mounting of glasses commonly called opera glasses." *Brit. Pat.* 2779 of 4th August, 1804. [119.]

(72) YOUNG, T. Ref. (1) in (46); more explicitly in M. v. Rohr's translation, "Zwei Abhandlungen von Thomas Young." *Z. f. ophth. Opt.* **11** 1923 (102–55), Tafeln III–VIII. [119, 123.]

DISCUSSION

Prof. F. J. Cheshire: The Society and Prof. von Rohr are to be congratulated on the paper which has just been read. There is no doubt that it will be accepted in the future as a classical contribution to the subject. I can assure Prof. von Rohr that the members of the Society are always delighted to sit at his feet and hear anything he has to say, especially on the subject which he has made so peculiarly his own—historical optics. What always impresses me is the thoroughness with which the author does his work. I feel that Prof. von Rohr, unlike Boaz, has not left many ears of corn behind him for any Ruth that follows him in the field of his research to glean.

Mr T. Smith: I should like to express, what I am sure has been in the mind of everyone who has listened to this lecture, our gratitude to Prof. von Rohr for presenting to us his account of the London opticians, our appreciation of his presence here this evening to tell us in person about these past masters of the optical arts, and not least our admiration for his unsparing labour and his perseverance in exploring so thoroughly, under conditions by no means easy, those avenues which were open to him. When I think of Prof. von Rohr's wide knowledge of these men, concerning whom most of us, though living in the same land, can only admit our ignorance, I am forcibly reminded of some observations made by the late Lord Rayleigh when addressing the Royal Society. Lord Rayleigh pointed out that workers in optics seemed to be unusually ignorant, not merely of what had been accomplished by workers in their own subject in other lands, but even of the work of their own countrymen. He went on to emphasise the importance of a knowledge of what had been accomplished in the past, and exhorted those who had acquired such knowledge to lose no opportunity of imparting it to others, and particularly to younger workers who had not yet travelled far on their course. We have to-night enjoyed an opportunity, the like of which is all too rare, of hearing about some of the pioneers whose contributions to our subject have lain more on the artistic than on the strictly scientific side. The importance of their influence on the varying fortunes of the craft in its development from what may appear to us in some ways its rude beginnings to the finest achievements of modern times will not escape the serious student of optics, and we all desire to express our warmest thanks to Prof. von Rohr for coming here and helping us, through his very careful investigations and cautious reconstructions, to appreciate better some of the outstanding personalities and events in this important period of optical history.

Mr R. S. Whipple: I should like to join in thanking Prof. von Rohr for his delightful lecture. All those who have read Prof. von Rohr's papers dealing with the history of spectacles must be impressed with the thoroughness of his work.

We are apt to criticise the early workers in physics for the fact that they did not know the work of their contemporaries, but it is impossible for us to realise the difficulties against which they had to contend. News travelled very slowly and there were no scientific journals such as *Nature* to which discoveries could

be communicated. There was no alternative but either to write a letter to a friend describing an invention or a new discovery, or to publish a book. These difficulties, as we know, were responsible for a great deal of plagiarism. Even in the twentieth century the difficulty of the work of two workers seriously overlapping has not been entirely overcome.

Prof. von Rohr's address has been most inspiring, and we all hope that he will be long spared to continue his researches into the history of English opticians and their work.

Prof. A. F. Pollard: I am glad to have the opportunity of adding my thanks for the privilege I have enjoyed with others to-night in listening to this masterly and fascinating paper.

Though it is not the duty of a Secretary to take up the time of his Society with unconsidered questions I would like to have Prof. von Rohr's opinion upon a matter which concerns the obscure dawn of ophthalmological optics. Govi* has stated that the Emperor Nero, who was undoubtedly short-sighted if the passages in Pliny have been correctly construed, used the convex† surface of sapphire to view distant objects by reflection. Does the author accept these conclusions of Govi? (I have used the general term sapphire in contradistinction to Govi's emerald. The ancients confounded many different stones under the name of emerald. The Latin word *smăragdus* implied a transparent precious stone of a bright green colour and included not only our emerald but also the beryl, jasper, malachite, etc. The term sapphire in the mineralogical sense implies the precious transparent varieties of the mineral corundum, the sesquioxide of aluminium, embracing the Oriental amethyst, Oriental topaz, and Oriental emerald as well as the ruby and is not necessarily limited to the azure varieties of corundum.)

Mr H. H. Emsley (communicated): This further paper of Prof. von Rohr's on the history of optics is perhaps even more fascinating than the previous ones. The author leaves no stone unturned in his attempt to arrive at the true facts. There is one small point upon which I should like to have Prof. von Rohr's opinion. At one time the deeply curved spherical lenses were called *coquille* and *mi-coquille*, having respectively, I think, base curves of 12 and 6 D. These terms appear to have fallen into disuse in favour of the term *meniscus* as far as the ordinary worked spectacle lenses are concerned, but are still used to some extent in connection with globular lenses for goggles. Can Prof. von Rohr give some information as to the origin of the term *coquille* and the manner in which it has come to be applied only to globular lenses?

Mr T. H. Court (communicated): In reference to John Marshall's invention of the method of grinding a number of lenses at one time on a block in a spherical tool it may be of interest to recall the statement of Richard Walker, Secretary of the Royal Society (posthumous Works of Robert Hooke, 1705, Preface, p. x):

* Govi, "Il microscopio composto inventato da Galilei," *Atti R. Accad. Sci. Fis. Mat. Napoli.* 2, Ser. 2a, 1888 (1–33). A translation is to be found in *Journ. Roy. Micr. Soc.* 1889 (574–598).

† See bottom of p. 581, *Journ. Roy. Micr. Soc.* 1889, also note (24) of the original paper.

"I remember Mr Marshall when he desired the Society's approbation of his new method of grinding spectacles and other optic glasses owned he had the first intimation of it from a hint of Mr Hooke's in this book (the *Micrographia*, 1683) about the polishing many very small microscopic object glasses at once."

Mr D. Baxandall (communicated): Prof. von Rohr has given us a most interesting and valuable paper, and I hope that when the paper is printed, with the references to the numerous sources from which he has drawn his information, attempts may be made to fill in the gaps which he has indicated.

With regard to Wollaston's periscopic spectacles, Imison (*Elements of Science and Art*, New Edition, 1808, vol. I, p. 402) states: "The advantage of these glasses ...has been sufficiently proved by numerous experiments on different persons; and they are manufactured by Messrs Dollond, London, who have a patent for their exclusive sale." In Rees's *Cyclopaedia*, 1819 (art. "Spectacles") it is stated that "Dr Hyde Wollaston's periscopic spectacles are now much in use." Reference is also made to "a new species of glasses...lately introduced at Paris, made by Chamblant, Optician, Rue Basse, Poste St Denis." These spectacles embodied the lenses with crossed cylindrical surfaces to which Prof. von Rohr has referred, and were called "conserves." The writer of the Article in Rees states that they were designed "with a view of obtaining the same effects as Dr Wollaston's periscopic spectacles."

The date of invention and sale of the monocle may be placed a little earlier than 1807, as suggested by Prof. von Rohr. The term "monocle," so far as I can find, did not come into use in England until a little after the middle of the 19th century. The instrument was usually designated "eye-ring," "single eye-glass," "quizzing-glass," or (less often) "quizzer." Murray's *Dictionary* gives the following quotations: "The prizes consisted of shawls, parasols, handkerchiefs, quizzing-glasses, etc." (*European Magazine*, 1802, June, p. 500). "'You must have a quizzer.' 'What is that?' said Edward. 'Oh, an eye-glass'" (*Winter in London*, 1806, II, 83). "A quizzing-glass was stuck in his right eye" (S. Warren, *Ten Thousand a Year*, 1840–1, ed. Warne).

In connection with the simple microscopes made from precious stones, it may be of interest to mention that the first diamond lens, made by Andrew Pritchard in 1824, has recently been presented to the Science Museum by Miss Spiller (his grand-daughter) together with Dr Goring's autograph letter of January 3rd, 1825, referring to his testing of the performance of the lens.

Prof. von Rohr's paper is full of interest, and I look forward with great pleasure to studying it in detail when it is published in the *Transactions*.

Prof. von Rohr (partly communicated): My knowledge regarding the point raised by Mr Emsley is not complete. There is no doubt that in early times (before 1791) watch dials were—after an English model—covered with rather deeply curved afocal lenses which were at that time made in Germany from *blown* glass spheres and called "Uhrgläser," i.e. watch-glasses (see also Ref. (46), p. 4, note 2). This last expression seems to have remained in everyday use, for in 1858 E. Busch

of Rathenow called certain afocal spectacle lenses "Uhrgläser" when the famous Berlin ophthalmologist A. v. Graefe ordered deeply curved coloured afocal glasses for protection against dazzling light. Some years later—certainly in 1867—the Viennese ophthalmologist K. Stellwag v. Carion described these "Uhrgläser" as "Muschelbrillen," i.e. shell-shaped spectacle glasses (see also Ref. (46), p. 73). When I myself found (Ref. (4), p. 71) in later (American and English) price lists the expressions "Mi-Coquille," "Coquille," I took them to be translations of the German designations "Halbmuschelgläser," "Muschelgläser" and assumed that they did not date so far back as 1867.

With regard to the use of the word meniscus, I think it possible that rather early some manufacturers wished to distinguish between afocal protective lenses of Coquille form and (mostly not so deeply curved) meniscus lenses with finite focal lengths.

As this information is not altogther satisfactory, I shall be very glad if some of my readers will interest themselves in this subject.

In answer to Prof. Pollard's question regarding Nero's eye-help I should like to refer to the first pages of a certain paper of mine cited under M. v. Rohr (45) in Ref. (46). I mentioned there that I myself tried to correct my own myopia with a convex mirror of power about -7 D and that I was quite satisfied with the correction obtained.

To-day I am far from sure that this knowledge may hold good in Nero's case for the following reasons:

(i) The ophthalmologist Prof. Greeff does not agree with the supposition of Nero's short-sightedness but rather thinks he had presbyopic or hypermetropic eyes.

(ii) I should also lay greater stress on the different sense of Pliny's meaning of the word concave—Idem plerumque et concavi ut visum colligant—that seems to follow from rings, adorned with concave emeralds, which have been excavated in our time. I gave some details in the paper to which reference has been made.

Summing up, I do not think that Nero used any green stone with a regularly curved (i.e. optically worked spherical) surface as an eye-help, but he may have used the green colour of the light reflected or refracted by such a stone as a means of invigorating his eyes. This would be in best agreement with the whole passage preceding Pliny's tale of Nero's emerald.

Referring now to Messrs Court and Baxandall, I can only express my sincerest thanks for much valuable information received by their communications. I really think that the knowledge about John Marshall's work as well as the early English opinions of Wollaston's periscopic glasses and the most interesting details about the "eye-rings" as early as 1802 must be of very great value to everybody interested in spectacle history.

I am certainly heartily grateful for your generous reception of my paper, but think it a simple duty towards my helpers to point back to my introductory sentences: it is only by mutual help that we may hope to value the work of our optical fathers.

HUYGENS' PRINCIPLE AND THE PHENOMENA OF TOTAL REFLEXION

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ABSTRACT. In this paper the phenomena of total reflexion are considered, *de novo*, from the standpoint of the Principle of Huygens, no use whatever being made of the Fresnel formulae for reflexion and refraction. Huygens' principle enables us to evaluate the disturbance appearing in the second medium when light is incident on the boundary between two media and is totally reflected into the first medium. The disturbance takes the form of a superficial wave moving parallel to the boundary. The existence of such a superficial wave is then shown to involve, as a necessary consequence, an *acceleration* of the reflected wave with reference to the incident wave, the acceleration being zero at critical incidence and increasing to half an oscillation at grazing incidence. The intensity of the superficial wave is at critical incidence greater for the component having the magnetic vector parallel to the surface, but diminishes more rapidly with increasing incidence than for the component having the electric vector parallel to the surface; the phase-advance reaches its maximum value correspondingly sooner. The phase-angle between the two components is evaluated and found to be an *acute* angle, in agreement with the classical treatment based on the Fresnel formulae, but in disagreement with the conclusions of Lord Kelvin and Schuster. The source of error in the Kelvin-Schuster treatment is pointed out. Experimental evidence regarding the magnitude of the phase-advance of each component separately is available and is in agreement with the classical theory.

Finally, a method is described by which the distribution of intensity, state of polarisation, and direction of flow of energy in the superficial wave may be studied experimentally.

1. Introduction

In Chapter III of his celebrated treatise on light, Christian Huygens applied his principle of the superposition of elementary wavelets to the explanation of the phenomena of reflexion and refraction, and showed that the absence of a refracted wave and the increased intensity of reflexion for incidences exceeding the critical angle follow from his principle as simple consequences. The principle of Huygens is thus the natural avenue of approach to the phenomena of total reflexion from the standpoint of wave-theory. Following Fresnel, however, the treatment of total reflexion usually given is based on the formulae for reflexion and refraction obtained by him, a suitable mathematical interpretation being given to the angles of refraction which become imaginary when the incidence exceeds the critical angle. While this

method may be mathematically elegant, it leaves the physical aspects of the problem somewhat obscure. Moreover, there has been some controversy about the actual magnitude and sign of the changes of phase occurring in total reflexion. Lord Kelvin*, in his *Baltimore Lectures*, discussed the subject at great length on the basis of the mechanical theory of light and claimed that the classical interpretation accepted for 80 years was in error. His views were supported by Schuster† in his book on optics, while Bevan's observations‡ on Lloyd's fringes in internal reflexion and Drude's discussion§ of the Fresnel formulae on the electromagnetic theory, on the other hand, appeared to support the classical interpretation. Prof. Schuster has, however, reiterated his views in the new edition of his book‖, and in a recent paper¶ claims that Drude's electromagnetic treatment is in error. In view of these facts, it would seem that an independent treatment of total reflexion, based directly on physical principles, and making no use whatever of Fresnel's formulae must be of value. It is proposed in this paper to supply such a treatment.

2. The Superficial Wave in the Second Medium

The method of approach which we shall adopt is that indicated by the author in a recent paper**. We regard the disturbance in the second medium as arising from the superposition of the wavelets radiated from different elements of the bounding surface and determine it by evaluating the integral which expresses the result of such superposition.

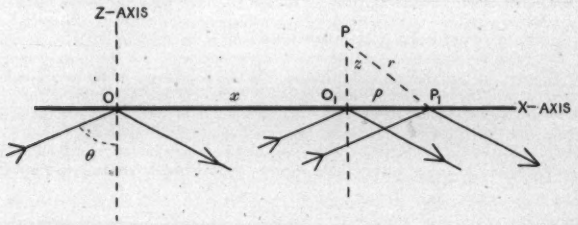

Fig. 1

In Fig. 1 the plane of incidence is taken to be the plane of the paper. The origin of co-ordinates O is taken to be on the surface at which total reflexion occurs, the latter coinciding with the xy-plane ($z = 0$), and the plane of incidence with the xz-plane. In accordance with the Principle of Huygens, the effect at a point P

* Kelvin, *Baltimore Lectures*, 1904 (386–406).
† A. Schuster, *Theory of Optics*, 2nd edn., p. 54.
‡ P. V. Bevan, *Phil. Mag.* **14** 1907 (503).
§ P. Drude, *Theory of Optics*, English translation, pp. 278–284.
‖ A. Schuster and J. W. Nicholson, *Theory of Optics*, 3rd edn., p. 54.
¶ A. Schuster, *Proc. Roy. Soc.* A **107** 1925 (15).
** C. V. Raman, *Proc. Ind. Assoc. Cultn. Science*, **9** 1926 (271).

in the second medium (co-ordinates x, o, z) is to be found by superposing the effects of the wavelets radiated from different elements of the bounding surface.

Drop a perpendicular PO_1 on the surface and divide the surface into circular zones with O_1 as centre. Denoting O_1P_1 by ρ, where P_1 is any arbitrary point on the surface, we have $PP_1 = r = (z^2 + \rho^2)^{\frac{1}{2}}$. An element of area on the surface is $\rho\, d\rho\, d\phi$ and the projection of ρ on the x-axis is $\rho \cos\phi$. If a train of light-waves of period T is incident on the boundary between two media in which the velocities of light are respectively V_1 and V_2, the refractive index of the second medium relatively to the first, $\frac{V_1}{V_2}$, being n, we may express the disturbance in the first medium due to the incident waves in the form

$$A \cos\left\{\frac{2\pi t}{T} - \frac{2\pi\,(x \sin\theta + z\cos\theta)}{V_1 T} - \tfrac{1}{2}\delta\right\} \qquad \text{.....(1),}$$

where θ is the angle of incidence.

The disturbance due to the wavelet radiating from the elementary area $\rho\, d\rho\, d\phi$ at P_1 and reaching P may be assumed to be of the form

$$\frac{k_1 A}{V_2 T} \cos\left\{\frac{2\pi t}{T} - \frac{2\pi\,(x + \rho\cos\phi)\sin\theta}{V_1 T} - \frac{2\pi r}{V_2 T}\right\} \frac{\rho\, d\rho\, d\phi}{r} \qquad \text{.....(2).}$$

It will be seen from (1) and (2) that we have assumed a difference of phase $\frac{1}{2}\delta$ (for the present undetermined) between the disturbance incident on any element of the surface and the secondary wavelet starting out from it. Such a difference of phase can conceivably exist, though, of course, its value may be zero in special cases. The numerical factor k_1 appearing in the amplitude of the wavelet is also for the present undetermined. The whole effect at the point P is found by integrating (2) over the entire area of the surface. Integrating first with respect to ϕ between the limits o and 2π, the result appears in the form

$$A_1 \cos\frac{2\pi}{T}\left(t - \frac{x\sin\theta}{V_1}\right) + A_2 \sin\frac{2\pi}{T}\left(t - \frac{x\sin\theta}{V_1}\right) \qquad \text{.....(3),}$$

where

$$A_1 = \frac{k_2}{V_2 T}\int_0^\infty A \cdot J_0\left(\frac{2\pi\rho\sin\theta}{V_1 T}\right) \cos\frac{2\pi r}{V_2 T} \cdot \frac{\rho\, d\rho}{r} \qquad \text{.....(4),}$$

and

$$A_2 = \frac{k_2}{V_2 T}\int_0^\infty A \cdot J_0\left(\frac{2\pi\rho\sin\theta}{V_1 T}\right) \sin\frac{2\pi r}{V_2 T} \cdot \frac{\rho\, d\rho}{r} \qquad \text{.....(5),}$$

where k_2 is proportional to k_1 and is therefore undetermined for the present.

Integrals (4) and (5) are of standard types which have been evaluated by H. Lamb*. When $\sin\theta$ is greater than $\frac{V_1}{V_2}$ or n, which is the condition for total reflexion, the integral (5) vanishes, and the integral (4) reduces to the form

$$A_1 = \alpha A \cdot e^{-\frac{2\pi}{TV_2}\cdot\sqrt{\frac{\sin^2\theta}{n^2} - 1}\,\cdot z},$$

* H. Lamb, *Proc. Lond. Math. Soc.* 7 1909 (140).

where σ is a numerical constant which remains to be determined. The disturbance in the second medium is thus of the form

$$\sigma A . e^{-\frac{2\pi}{TV_2}\cdot\sqrt{\frac{\sin^2\theta}{n^2}-1}\,.\,z} . \cos\frac{2\pi}{T}\left(t-\frac{x\sin\theta}{nV_2}\right) \qquad \text{.....(6),}$$

which expresses a wave of amplitude σA at the surface but decreasing exponentially with z and propagated parallel to the surface along the x-axis. We shall consider the magnitude of the energy-flow in the superficial wave a little later, but it is obvious from (6) that it is entirely parallel to the surface, and thus the energy-flux *across* any element of area of the surface must be zero.

3. Change of Phase in Total Reflexion

Since there is no energy-flux *across* the boundary, it follows that the amplitudes of the incident and reflected waves must be equal. It can be easily seen, moreover, that the existence of a superficial wave of the form shown in (6) involves as a necessary consequence a difference in the phases of the incident and reflected waves at the boundary. To prove this, we have only to consider the continuity of the disturbance on the two sides of the boundary. It is convenient to consider separately the cases in which the electric vector and the magnetic vector in the incident waves are respectively parallel to the surface of separation between the two media.

Case 1. *Light polarised in the plane of incidence.* In this case we are concerned with the electric force E_y parallel to y, and identify the amplitude A appearing in our formulae with the amplitude of this vector. In order that E_y may have the same value on both sides of the boundary, we must have, when $z = 0$, the sum of the electric forces in the incident and reflected waves equal to that in the superficial wave. In order to obtain this result, using the expressions (1) and (6) already derived for the incident and superficial waves respectively, we are compelled to assume that the electric force in the reflected wave is given by

$$A\cos\left\{\frac{2\pi t}{T}+\frac{2\pi\,(x\sin\theta-z\cos\theta)}{V_1T}+\tfrac{1}{2}\delta\right\} \qquad \text{.....(7),}$$

and find that the factor σ appearing in the amplitude of the superficial wave is connected with the phase-advance δ of the reflected wave relatively to the incident wave by the simple relation

$$\sigma = 2\cos\tfrac{1}{2}\delta \qquad \text{.....(8).}$$

We shall use σ_s and δ_s to signify the values of σ and δ in the present case. To find a second relation connecting them, we note that the component of the magnetic force H_x parallel to the surface must also be continuous at the boundary. We must therefore have $\frac{\partial E_y}{\partial z}$ the same on both sides of the boundary. Differentiating (1), (6), and (7) with respect to z, and applying this condition, we obtain very readily

$$\sigma_s^2=\frac{4\cos^2\theta}{1-n^2}, \quad \text{and} \quad \tan\tfrac{1}{2}\delta_s=\frac{\sqrt{\sin^2\theta-n^2}}{\cos\theta} \qquad \text{.....(9).}$$

At the critical incidence $\sin\theta = n$, and therefore $\frac{1}{2}\delta_s$ is either zero or any multiple of π. The angle δ_s is either zero or any multiple of 2π. We therefore take δ_s to be zero at the critical incidence. For incidences greater than the critical angle, $\tan\frac{1}{2}\delta_s$ is positive, and becomes infinite at grazing incidence. Accordingly, δ_s is positive and increases from 0 to π, as we pass from critical to grazing incidence.

Case 2. *Light polarised at right angles to the plane of incidence.* In this case the magnetic force is parallel to the y-axis, and we identify it with the vector A appearing in our formula. Since H_y must be the same on both sides of the boundary, we obtain the same expressions (7) for the reflected wave as in the preceding case, A being now understood to refer to the magnetic force in the incident wave. Since the component of the electric force E_x parallel to x must be the same on both sides of the boundary, $\dfrac{\partial H_y}{\partial z}$ in the second medium must be n^2 times as large as its value in the first medium. Differentiating (1), (6), and (7) with respect to z, and applying this condition, we obtain a second relation between σ_p and δ_p in addition to the relation $\sigma_p = 2\cos\frac{1}{2}\delta_p$ deduced as in the preceding case. In this way, we find

$$\sigma_p^2 = \frac{4n^4\cos^2\theta}{(n^4-n^2)+\sin^2\theta\,(1-n^4)} \quad \text{and} \quad \tan\tfrac{1}{2}\delta_p = \frac{\sqrt{\sin^2\theta - n^2}}{n^2\cos\theta} \qquad \text{.....(10).}$$

Arguing exactly as the preceding case, we see that the phase of the reflected wave is *advanced* relatively to that of the incident wave by a quantity δ_p which is zero at critical incidence and increases to π at grazing incidence.

4. Difference of Phase of Components

Our investigation has shown that the incident and reflected waves are in the same phase at critical incidence, and are opposed in phase at grazing incidence. This is true both in Case 1 and Case 2 and hence the angle $(\delta_p - \delta_s)$, which represents the difference in the phase-advance in the two cases, is zero both at critical incidence and at grazing incidence. Since $n^2 < 1$, it can be seen from (9) and (10) that at intermediate incidences $\tan\frac{1}{2}\delta_p$ is greater than $\tan\frac{1}{2}\delta_s$. In other words, the phase-advance in Case 2 is greater than in Case 1, and $(\delta_p - \delta_s)$ is positive. From (9) and (10) we derive the following formulae:

$$\tan\delta_s = \frac{2\cos\theta\sqrt{\sin^2\theta - n^2}}{(n^2-1)+2\cos^2\theta}, \qquad \cos\delta_s = \frac{n^2-1+2\cos^2\theta}{1-n^2} \qquad \text{.....(11),}$$

$$\tan\delta_p = \frac{2n^2\cos\theta\sqrt{\sin^2\theta - n^2}}{(n^4+1)\cos^2\theta-(1-n^2)}, \quad \cos\delta_p = \frac{(n^4+1)\cos^2\theta-(1-n^2)}{(n^4-1)\cos^2\theta+(1-n^2)} \qquad \text{.....(12),}$$

$$\tan\tfrac{1}{2}(\delta_p-\delta_s) = \frac{\cos\theta\sqrt{\sin^2\theta-n^2}}{\sin^2\theta}, \quad \cos(\delta_p-\delta_s) = \frac{2\sin^4\theta-(n^2+1)\sin^2\theta+n^2}{(1+n^2)\sin^2\theta-n^2} \qquad \text{.....(13).}$$

Formula (13) is identical with that derived by Drude. From our formulae it follows that $(\delta_p - \delta_s)$ for glass is always an acute angle, in agreement with what

had generally been accepted as true. According to Kelvin and Schuster, however, the phase of the reflected wave is advanced in Case 1, and retarded in Case 2, and the difference in phase of the two components is represented by an obtuse angle. Since the method adopted in the foregoing treatment is based directly on first principles and gives the quantities under consideration in an entirely unambiguous manner, it would seem that the grounds on which Kelvin and Schuster base their criticism of the classical treatment must be invalid. We shall presently see that this is actually the case.

5. The Kelvin-Schuster Treatment

For our purpose it is sufficient to examine the argument in the form in which it is presented by Schuster in his recent paper in which he criticises Drude's treatment, which is, in fact, substantially the same as that put forward by Kelvin. It rests on the supposed necessity for assuming that the well-known Fresnel coefficients of reflexion for the parallel and perpendicular components of vibration must be both numerically and algebraically equal to each other in the limiting case of normal incidence. The argument rests on a fallacy which will become clear when we recollect that in order to fix the direction of a ray in a unique manner, we require to know the positive direction of two *vectors*, namely the electric and magnetic vectors. The direction of the ray is perpendicular to both, and the phase of the oscillation, in it may be determined indifferently from the phase of either. In the case of normal incidence, the direction of the ray is reversed on reflexion, so that if the electric vectors in the incident and reflected pencils are in the same direction, the magnetic vectors are opposed to each other, and vice versa. If, as proposed by Schuster, the positive direction of a vector is always to be so chosen that the positive directions of the vector for the incident and reflected pencils become coincident for normal incidence, we should be led to the absurd conclusion that the phase of a ray on normal reflexion is electrically reversed but is magnetically unaltered. It is necessary, in fact, in order to obtain correct results, to assume a rule of signs for vectors lying in the plane of incidence which is exactly opposite to that suggested by Schuster. The scheme adopted by Drude is the correct one, and accordingly gives correct results. All ambiguity or difficulty may be avoided, however, by taking as the phase of a pencil of light, the phase of the vector (electric or magnetic as the case may be) which has a direction perpendicular to the plane of incidence. The direction of such vector remains invariable when the angle of incidence is altered, and no special convention as to sign is necessary. As a matter of fact, the Fresnel formulae for reflexion and refraction can easily be derived by considering only the vector (electric or magnetic as the case may be) perpendicular to the plane of incidence and writing down the condition for its continuity at the boundary, as also for the equality of the normal flux of energy through unit area of the boundary on either side of it. The two Fresnel coefficients then appear with *opposite* signs, and since the phase of the reflected ray must be

identical for the electric as for the magnetic vibration, the same result must also be valid when we consider the vectors lying in the plane of incidence.

The analytical necessity for so fixing the positive directions of vectors lying in the plane of incidence that the two Fresnel coefficients appear with opposite signs becomes very clear when we consider the case of a circularly-polarised ray incident normally on a surface and reflected from it. In this case, no doubt, both the components of the ray are reflected under the same conditions and it might seem, at first sight, that their relative phase should remain unaltered. In reality, however, owing to the reversal of the direction of the ray, if it has right-handed circular polarisation before reflexion, it has left-handed circular polarisation after reflexion, and this is analytically equivalent to a reversal of the phase of one of the components relatively to the other. It is precisely in order that the physical and analytical requirements of the case might both be complied with, that the signs of the vectors have to be taken in the manner chosen by Drude. The convention adopted by him is, in fact, merely the well-known Ampère rule of signs in another form. It has the effect of making vectors in the incident and reflected rays, which lie in the plane of incidence and which are both in the same phase and parallel to each other at grazing incidence, continue to be in the same phase, though (geometrically) oppositely directed at normal incidence unless, of course, in the interval a real physical change in their relative phase has occurred.

6. Polarisation and Intensity of Superficial Wave

We have already had occasion to consider the components of the electric and magnetic vectors parallel to the boundary in the superficial wave and their relation to the expressions (1), (6), and (7). The components of the electric and magnetic forces perpendicular to the surface may be similarly found by applying the boundary conditions. It appears that the components E_y and H_x in Case 1 differ in phase by a quarter of an oscillation, and the components H_y and E_x in Case 2 similarly differ in phase. Hence, in either case, the energy-flow along the axis of z is zero. The components H_x and E_y in Case 1 and the components E_x and H_y in Case 2 have, however, identical phases, and therefore give rise to energy-flow parallel to the axis of x proportional to H_zE_y and E_zH_y respectively. The ratio of the energy-flow in the two cases is found to be

$$\frac{n^2\sigma_s^2}{\sigma_p^2}, \text{ and } \textit{not } \frac{\sigma_s^2}{\sigma_p^2}.$$

Why the factor n^2 appears is most easily seen on considering the case in which the incidence is just at the critical angle; in this case $\sigma_s^2 = \sigma_p^2$, but in the emergent ray, which is parallel to the surface, the intensity of its s component is n^2 times that of the p component. In other words, since $n^2 < 1$, the superficial wave is polarised with the stronger component of the electric vector perpendicular to the surface.

When the expression for the flow of energy in the superficial wave is plotted against the angle of incidence θ, it is found to fall off rapidly from its maximum value for critical incidence to zero value at grazing incidence. In other words, the

intensity of the superficial wave falls off to zero as the angle of incidence is increased. σ_p^2 falls off more quickly than σ_s^2. Since $\sigma_p = 2\cos\frac{1}{2}\delta_p$ and $\sigma_s = 2\cos\frac{1}{2}\delta_s$, the intimate relation between this fall in intensity and the change of phase in reflexion will be readily understood.

7. Experimental Study of Superficial Wave

The existence of a superficial wave has been demonstrated in different ways. Stokes used the method of observing Newton's rings between a prism and a lens, when the angle of incidence exceeded the critical angle, and Quincke also investigated it by a method very similar in principle. By placing small particles in contact with the surface and thereby causing them to scatter light, the superficial disturbance has also been made evident. This method is, however, only qualitative. The present writer has shown in a recent paper* that when a totally-reflecting surface is of finite extent, as indeed is inevitable, the superficial wave gives rise to diffraction effects which can be observed and photographed at great distances from the surface. The edges of the surface, in fact, act as sources of secondary radiation in the same way

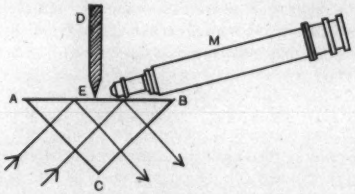

Fig. 2

as the boundary of any fully illuminated diffracting aperture. In order, however, to observe the disturbance in the second medium at points very close to the surface itself and investigate it in detail, an entirely different method has been devised by the writer. This is indicated in Fig. 2.

AB is the hypotenuse of a right-angled glass prism *ABC* at which total reflexion occurs. *DE* is a fresh "Gillette" razor-blade of which the sharp edge *E* is placed as nearly as possible parallel to the surface *AB*. A fine slow motion, such as that provided on interferometers, enables the razor-blade to be moved forward or backward so that the edge approaches or recedes from the face of the prism by fractions of a wave-length. The microscope *M* is focussed on the razor-edge; the latter is usually invisible unless some diffuse illumination is provided in the field of view. If the axis of the microscope be in the plane of incidence and the razor-blade be placed perpendicular to the plane of incidence and slowly advanced within a very small distance of the surface, it is seen as a luminous line in the microscope. The distance of approach or removal from the surface within which

* C. V. Raman, *Phil. Mag.* **50** 1925 (812).

the luminosity of the edge is visible is a measure of the thickness of the layer within which the superficial disturbance in the second medium is sensible.

The principle of the method depends on the well-known property of a sharp and highly polished metallic edge to diffract a stream of light falling upon it through considerable angles and to appear as a luminous line when viewed in suitable directions. Simple observations with a sharp razor-edge held in an ordinary parallel pencil of light show that the directions in which the luminosity of the edge is visible depend on the position of the edge relatively to the stream of rays. In the general case when the edge is inclined to the light-stream, the luminosity is visible only when the direction of observation is any generator of a cone having the edge for its axis and the direction of the undiffracted rays for another generator. When the stream of light falls normally on the diffracting edge, its luminosity is visible in any direction lying in a plane perpendicular to the edge.

From what has been stated above it is clear that the observations of the luminosity of the edge in the arrangement shown in Fig. 2, when it approaches sufficiently close to the surface, prove that there is actually a stream of energy in the second medium travelling parallel to the surface in the plane of incidence. The method enables the rate at which the intensity in the superficial wave decreases with increasing normal distance from the surface to be determined. It is found that, when the incidence is just at the critical angle, the intensity of the superficial wave is a maximum and is quite comparable with that of the incident and reflected beam. But as the incidence is increased the intensity falls off more or less quickly and becomes zero at very oblique incidences. The decrease of the intensity of the superficial wave with increasing normal distance from the surface is very rapid; when the incidence is not much greater than the critical angle, say about 50°, the luminosity is perceptible when the edge is within a wave-length or so from the surface. For larger angles of incidence, 60° or more, the decrease is far more rapid, and the luminosity is perceptible practically only when the razor-edge is in actual contact with the surface of the prism. When the incident light is unpolarised, the luminosity of the edge, observed as nearly as possible parallel to the surface, is found to be strongly polarised with the strong component of the electric vector perpendicular to the edge.

8. Direct Measurement of Phase-Changes

It has already been mentioned that Bevan, by observations on Lloyd's fringes formed by internal reflexion, verified the fact that the phase-differences δ_s and δ_p between the incident and totally-reflected waves amount to π at grazing incidence. In an investigation on the colours of mixed plates*, it was shown by the present writer that part of the light falling upon the curved edges of the air-bubbles contained in these plates is totally reflected at various angles between grazing and critical incidence and interferes with another part which also emerges after two refractions through the curved edges. The positions of the maxima and minima

* C. V. Raman and K. Seshagiri Rao, *Phil. Mag.* **42** 1921 (679).

in these interferences depend on the phase of the totally-reflected light, and the good agreement found between the observed and calculated values is a confirmation of the correctness of the formula used for calculating the phase-difference. The method also enabled the difference $\delta_p - \delta_s$ to be directly observed and measured, and this was found to be an *acute* angle. It would appear quite practicable to arrange a simple interference experiment in which the phase-advances δ_p and δ_s may be measured separately and compared with each other.

9. Conclusion

The method of the knife-edge described above was shown to be practicable in observations made at the author's suggestion by Mr D. P. Acharya and was later more fully tested by Mr S. C. Sirkar. Further observations by this method (using stronger illumination), and an experimental study of the state of polarisation of light scattered by small particles in the vicinity of a totally reflecting surface, would appear to be called for.

In conclusion, the author has much pleasure in referring to the valuable assistance received by him from Mr K. S. Krishnan in the preparation of the paper.

DISCUSSION

Mr T. Smith: It is gratifying to find that the total reflexion problem for a harmonic wave-train can be treated so thoroughly on the simple Huygenian principle. It would be still more satisfying to have a corresponding discussion in which events according to some of the modern quantum theories of light are considered; since these theories are still in their infancy we shall probably have to wait some time for an investigation of such special problems on these bases. Unlike the important question of phase, which relates essentially to the waves and is thus common to all theories, the question whether the real light energy, that is the light quantum, penetrates the second medium does not appear to be yet answered. It is obvious that there must be something in the nature of a superficial wave in the second medium—one can hardly imagine that conditions just on one side of a surface, while a train of waves is being reflected from the other side, are no different from those holding when no disturbance reaches the surface—but the energy of these waves is not necessarily identical with the energy of the light.

Mr J. W. Perry: The boundary condition here assumes the natural confines of the first and second media to be a common boundary surface. But it is found necessary to postulate a transition layer in order to explain the residual elliptic polarisation on reflexion at the boundary. It would be of interest if from the experimental study of the results obtained some indication were found serving to corroborate the existence of the transition layer.

Mr E. T. Hanson: Prof. Raman is to be congratulated upon his ingenious and interesting method of attacking the problem of total reflexion, which, strange to say, has been a stumbling-block to so many celebrated physicists and mathematicians. I am not, however, in entire agreement with him as to the advisability of using Huygens' principle in the way he has done. Kirchhoff's formula, which is derived by purely mathematical reasoning, might have been applied. But Huygens' principle is a concrete physical conception, which somewhat loses its meaning when reduced to the limiting equation (6) of Prof. Raman's paper, for, in this limiting case, no energy can be said to be radiated into space from the elementary secondary wavelets.

Drude's very careful treatment of the problem has always appeared to me to be excellent in every essential respect, and it is satisfactory to have Prof. Raman's alternative confirmation of its correctness, even though his method may be open to criticism.

Drude's attempt to explain how the energy passes from the first medium into the second medium and back into the first in the case of total reflexion appears to me to be incorrect, but the matter is perhaps of small importance. One of the most interesting phenomena at, or near, total reflexion, is that of the diffraction of a beam of light by a slit when the latter is placed inside the first medium and not too close to the surface at which total reflexion takes place. The explanation of the observed phenomena by the use of Huygens' principle and Fresnel's formulae is very instructive.

With regard to the superficial wave itself, apart from diffraction, the following remarks may be of interest. For angles of incidence equal to and greater than the critical angle it is possible to combine the incident and reflected wave systems into a single plane wave of variable amplitude. In fact, in the incident space, there is a plane wave travelling parallel to the interface, the amplitude varying harmonically along the wave-front. In the refracted space there is a plane wave also travelling parallel to the interface, the amplitude decreasing exponentially from the interface. These two wave systems, derived by theory, satisfy all the conditions of the mathematical problem. Now it can be shown that at critical incidence no energy is transmitted to and fro across the interface. The physical explanation appears to be, therefore, that the two systems of waves in the first medium adjust themselves to the velocity of a possible plane wave in the second medium, so that there is no reaction to the propagation of the electromagnetic displacements along the boundary.

Prof. Raman (communicated): Replying to Mr Perry's remark, it may be said that transition layers have but a small influence on the total reflexion of light (Drude, *Wied. Ann.* **43** 1891 (126) and Maclaurin, "Theory of Light," pp. 62 and 82). They may, however, be important in the total reflexion of X-rays, where the wave-length is much smaller. The effect of the transition layers in total reflexion is experimentally evident in observations on the scattering of light by liquid surfaces (*Proc. Roy. Soc.* A **109** 1925 (150)).

In reply to Mr Hanson, I may say that the simplest expression of Huygens'

principle is employed, as it answers the purpose sufficiently and avoids unnecessary mathematical difficulties. It must be remembered in this connection that Kirchhoff's principle is only one way of formulating the propagation of waves in an uninterrupted medium and, even as such, is not unique. In the present case we are concerned with the effects occurring at the boundary between two media, and not with a single uninterrupted medium.

With regard to the question of energy it is clear that the elementary wavelets entering into the second medium attenuate each other's effects by interference so completely that the actual energy conveyed by them is an infinitesimal quantity. I would interpret formula (6) as being just a mathematical expression of this physically intelligible result.

THE HARTMANN FORMULA FOR THE DISPERSION OF GLASS

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ABSTRACT. The Hartmann formula is found to be accurate within the limits of the Pulfrich refractometer. A number of glasses are graphed from their Hartmann constants, and it is seen that optical glasses can be divided into three well-marked classes, with linear relations between the constants in each class.

Introduction

The Hartmann formula $$n = n_0 + \frac{c}{(\lambda_0 - \lambda)^a}$$ is known to give an approximation to the measured refractive indices of a wide range of optical glasses throughout the visible spectrum, but hitherto the information about glass has been too scanty to enable us to gauge the precise utility of the formula for interpolation. Till within the last year or so, glass manufacturers have tabulated for their glasses the refractive indices for the three hydrogen lines C, F, and G' and for the sodium line D (or rather for the mean of the double lines D), but recently the catalogues of Schott and Gen. in Germany and of Parsons Glass Co. in England have made use of an extended series of reference lines, viz. the green e line (5461 Å), the blue g line (4359), and the violet h line (4047) of the mercury spectrum in addition to the old C and F lines of hydrogen, while the "standard" refractive index is given for the yellow d line of the helium spectrum (5875). Schott also tabulates the refractive index for the potassium A' line (7685), while Parsons makes use instead of the b line of helium. Opticians generally will welcome the change, for the lines chosen are convenient to obtain (in this respect the system is superior to that suggested by Gifford*) and fairly well cover the range required, with sufficiently small intervals†. In respect to the remaining divergence in use between the A and b lines, superiority would seem to lie with the latter as requiring no additional light source; indeed it seems a little inconsistent to retain the inconvenient potassium line while abolishing the D lines, all the drawbacks of which it shares, while possessing a few peculiar to itself. The b line, moreover, extends sufficiently far into the red end of the spectrum, as both the eye and the photographic plate are relatively insensitive to that colour.

* J. W. Gifford, *Trans. Opt. Soc.* **15** 1914–15 (187).

† J. W. Hasselkus, *Proc. Opt. Conv.* 1926 (925), where the matter is discussed.

Table I

Maker's designation	n_D	ν	n_0	c	λ_0	Errors in A'	C	d	e	g	$\lambda_0 + 1{\cdot}73\nu - 243{\cdot}3$
PARSONS											
FC	1·49429	67·9	1·47962	23·02	126·0	—	− 3	− 5	− 3	0	+ 0·2
BSC 2	1·51094	63·5	1·49506	24·44	133·5	—	− 3	− 4	− 4	− 1	+ 0·1
HC 4	1·51764	59·0	1·50070	25·63	140·6	—	− 2	− 2	− 1	− 1	− 0·6
5	1·51944	60·4	1·50275	25·34	139·1	—	− 2	− 2	+ 1	+ 1	+ 0·3
LBC	1·54008	59·7	1·52260	26·5	139·9	—	− 1	− 1	− 1	− 1	− 0·1
ZC	1·53587	58·1	1·51822	26·47	143·9	—	− 2	− 1	− 3	0	+ 1·1
MBC 2	1·57644	57·5	1·55732	28·72	144·1	—	− 1	+ 2	− 1	− 1	+ 0·3
3	1·56026	56·1	1·54133	28·15	147·2	—	− 1	− 1	− 1	− 1	+ 1·0
4	1·56431	55·7	1·54513	28·46	147·8	—	− 3	− 2	− 2	− 1	+ 0·9
DBC 1	1·59644	59·6	1·57699	29·62	138·1	—	− 3	− 2	− 2	− 1	− 2·1
3	1·61342	59·3	1·59341	30·32	139·9	—	− 2	− 3	− 2	0	− 0·8
5	1·60485	58·2	1·58487	30·13	142·0	—	− 1	− 1	− 1	− 1	− 0·6
9	1·62090	57·2	1·60013	31·21	143·5	—	− 1	0	− 1	− 1	− 0·8
10	1·61321	56·8	1·59268	30·68	145·4	—	0	0	0	− 1	+ 0·4
SC 2	1·52980	51·5	1·51067	27·92	154·0	—	− 1	− 1	− 2	− 1	− 0·2
TF 2	1·51507	56·4	1·49770	25·90	146·0	—	− 1	− 2	− 2	+ 2	+ 0·3
3	1·53042	52·0	1·51105	28·81	146·9	—	− 1	− 2	− 1	+ 1	− 6·4
BLF 2	1·54856	53·6	1·52933	28·34	150·5	—	− 2	− 1	− 1	− 1	− 0·1
3	1·58070	53·6	1·56051	29·72	151·4	—	+ 2	+ 2	0	− 2	+ 0·8
4	1·54925	52·4	1·52971	28·59	153·2	—	− 1	0	− 1	− 1	+ 0·6
ELF 1	1·55164	45·7	1·52986	30·81	165·0	—	− 2	− 2	− 1	− 3	+ 0·8
2	1·54886	45·3	1·52690	31·22	163·3	—	− 2	− 1	− 1	− 1	− 1·6
BF 1	1·58057	45·8	1·55773	32·34	165·0	—	− 2	0	− 2	− 2	+ 0·9
2	1·60483	43·8	1·58016	34·68	167·5	—	− 1	0	0	− 2	0·0
4	1·62274	39·6	1·59524	37·80	175·3	—	− 1	0	0	− 2	+ 0·5
LF 1	1·56745	43·8	1·54432	32·45	168·0	—	0	− 1	− 1	− 2	+ 0·5
2	1·56390	43·0	1·54042	33·08	166·8	—	− 2	+ 1	+ 1	− 1	− 2·1
4	1·58251	41·8	1·55778	34·51	170·0	—	− 1	− 1	− 1	0	− 1·0
5	1·57591	41·3	1·55117	34·49	170·3	—	− 2	0	− 2	− 1	− 1·6
DF 1	1·60545	38·0	1·57781	37·77	177·3	—	+ 1	0	− 1	− 2	− 0·3
2	1·61323	36·9	1·58445	39·22	178·2	—	− 1	0	0	− 3	− 1·3
4	1·62308	36·0	1·59234	40·32	180·1	—	+ 2	+ 1	0	− 2	− 0·9
EDF 1	1·65035	33·7	1·61765	43·71	185·1	—	+ 1	+ 3	+ 2	0	− 0·1
2	1·65336	33·6	1·62038	44·06	185·1	—	+ 1	+ 2	+ 1	− 3	+ 0·1
DEDF 1	1·74135	27·7	1·69746	56·73	196·1	—	+ 3	+ 4	+ 1	− 4	+ 0·7
2	1·76724	26·6	1·72048	59·94	199·1	—	+ 6	+ 8	+ 5	− 4	+ 1·8
CHANCE											
DBC	1·6234	56·3	1·60261	31·05	147·7	—	− 1	—	—	—	+ 1·8
VDF	1·6715	32·3	1·63671	46·36	187·5	—	− 1	—	—	—	+ 0·1
	1·7167	29·5	1·67640	53·17	190·9	—	− 1	—	—	—	− 1·4
SCHOTT											
FK 2	1·48807	70·6	1·47415	22·00	123·9	+ 9	—	− 2	− 2	− 1	+ 2·7
3	1·46450	65·7	1·45050	21·79	129·7	+ 7	—	− 2	− 2	− 2	+ 0·1
4	1·47828	65·9	1·46363	23·25	122·5	+ 11	—	− 1	− 1	0	− 6·8
BaF 1	1·55690	48·6	1·53597	30·03	160·3	+ 2	—	+ 1	0	0	+ 1·1
F 6	1·63636	35·4	1·60551	41·63	181·7	− 4	—	+ 1	0	− 3	− 0·4
BaSF 1	1·62606	39·1	1·59812	38·38	175·6	− 4	—	0	+ 1	− 2	− 0·1
2	1·66459	35·7	1·63274	42·88	182·4	− 4	—	+ 1	0	− 2	+ 0·9
4	1·65130	38·3	1·62178	40·37	177·1	− 3	—	+ 1	− 1	− 3	+ 0·1
SF 6	1·80518	25·5	1·75412	64·99	201·0	− 14	—	+ 2	+ 2	− 4	+ 1·8
KzF 4	1·57041	48·1	1·54875	31·15	159·5	+ 8	—	0	0	0	− 0·6
KzFS 3	1·57510	51·9	1·55407	31·37	146·0	+ 3	—	+ 1	0	0	− 7·5

NOTE. In applying the values given in Tables I and II and in the equation on p. 164, line 3, wavelengths are to be expressed in $m\mu$ and not in Ångström units (e.g. $\lambda_F = 486{\cdot}1$).

The new scale of wave-lengths in Ångström units, together with numbers proportional to their reciprocals, are shown below, with the old scale for comparison.

New scale			Old scale		
b	7065	1415		—	
C	6563	1524	*C*	6563	1524
d	5875	1702	*D*	5893	1697
e	5461	1831		—	
F	4861	2057	*F*	4861	2057
g	4359	2243	*G′*	4341	2304
h	4047	2471		—	

It will be seen that the two lines superseded, *D* and *G′*, are replaced by closely neighbouring lines *d* and *g*, so that no fear of rendering earlier calculations incomparable with later ones need deter the optician from adopting the new scale.

Application of Hartmann Formula

As in the Parsons catalogue the refractive indices are taken from readings on an accurate spectrometer, it seemed a favourable opportunity to put the Hartmann formula to the test. A number of representative glasses was chosen and the Hartmann constants calculated from the refractive indices for the *b*, *F*, and *h* lines, taking $a = 1{\cdot}2$. These lines represent the extremes of the spectrum and, considering the wave-length reciprocals, their mean (the mean of 1415 and 2471 is 1943, which is close to 2057, corresponding to the *F* line). From the Hartmann constants so found the refractive indices for the lines *C*, *d*, *e*, and *g* were found and compared with the published figures. Table I gives the results.

It will be seen that interpolation from the Hartmann formula gives an accuracy within the limits of error of the results obtained from the Pulfrich refractometer, which is sufficiently good for all requirements of the optician. This accuracy is not maintained at the ends of the glass list, i.e. for fluor crowns and extremely dense flints; these extreme glasses require slightly different values of *a*, as Table II shows.

Table II

Maker's designation	*a*	n_D	ν	n_0	*c*	λ_0	Errors in			
							C	*d*	*e*	*g*
FC	1·0	1·49429	67·9	1·47803	6·94	160·2	− 1	− 2	− 1	0
BSC 2	1·1	1·51094	63·5	1·49428	13·36	150·25	− 2	− 3	− 2	− 1
DEDF 2	1·35	1·76724	26·6	1·72342	147·0	178·65	+ 2	0	− 1	0

The validity of the Hartmann formula being established for a large number of glasses, it is justifiable to complete the list from other makers' lists, where it is not possible to use the same system of lines for computing the constants. So Table I contains glasses from Chance's and Schott's lists*, which were added to obtain a complete range of all the optical glasses at present made.

* For glasses in Schott's list the constants were found from the *C*, *F*, and *h* lines, while *C*, *F*, and *G′* were used with Chance's list.

It is well known that a linear law exists between λ and ν for optical glasses; the relationship is found to be

$$\lambda_0 = -1{\cdot}73\nu + 243{\cdot}3.$$

The last column in Table I shows the divergence of λ_0 from that given by the straight line law. The line being approximately established for a few glasses, λ_0 can be found for any other glass, to a first approximation at any rate. This greatly facilitates the work of computation.

The usual formula for the achromatism of two thin glasses in juxtaposition is $F_1/\nu_1 + F_2/\nu_2 = 0$, where F_1 and F_2 are the powers and $\nu = \dfrac{n_D - 1}{n_F - n_C}$. This may be written

$$(n_F - n_C)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) + (\bar{n}_F - \bar{n}_C)\left(\frac{1}{r_3} - \frac{1}{r_4}\right) = 0,$$

where the r's are the radii, or

$$A(n_F - n_C) + B(\bar{n}_F - \bar{n}_C) = 0.$$

From the Hartmann formula

$$n_F - n_C = c\left\{\frac{1}{(\lambda_F - \lambda_0)^{1.2}} - \frac{1}{(\lambda_C - \lambda_0)^{1.2}}\right\} = \frac{c(\lambda_C{}^{1.2} - \lambda_F{}^{1.2})}{(\lambda_F - \lambda_0)^{1.2}(\lambda_C - \lambda_0)^{1.2}} \text{ approximately,}$$

and the achromatic condition becomes

$$\frac{Ac}{(\lambda_F - \lambda_0)^{1.2}(\lambda_C - \lambda_0)^{1.2}} + \frac{B\bar{c}}{(\lambda_F - \bar{\lambda}_0)^{1.2}(\lambda_C - \bar{\lambda}_0)^{1.2}} = 0 \qquad \text{.....(1),}$$

or, with sufficient approximation,

$$\frac{Ac}{(\lambda_D - \lambda_0)^{2.4}} + \frac{B\bar{c}}{(\lambda_D - \bar{\lambda}_0)^{2.4}} = 0 \qquad \text{.....(2).}$$

For apochromatism, i.e. chromatic correction independent of the pairs of wavelengths chosen, it is seen from (1) that we must have

$$\lambda_0 = \bar{\lambda}_0{}^{*} \qquad \text{.....(3),}$$

and the condition becomes

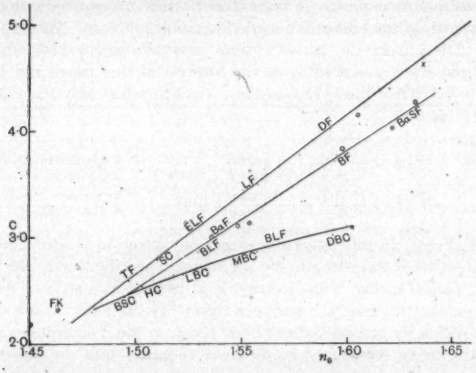
$$cA + \bar{c}B = 0 \qquad \text{.....(4).}$$

If a linear law exists between λ_0 and ν there can be no apochromatism, so that the suitability of a glass for reducing the secondary spectrum is at once apparent from its non-fulfilment of the straight line law (as shown in the last column of Table I), which is thus of value in differentiating glasses according to their utility for curing the secondary spectrum. It is seen that there is really only one glass useful in this respect, the TF 3 of Parsons (and similar glasses by Chance and Schott).

Probably the glass maker would prefer some arrangement of the glasses according to their composition rather than to their optical properties, and this the Hartmann constants allow us to do. Messrs Chance Bros. have published in their catalogue and in the *Proceedings of the Optical Convention*, 1926†, a graph of their

* This was pointed out by Moffitt, *Phys. Rev.* **11** 1918 (144).
† W. H. S. Chance and W. M. Hampton, *Proc. Opt. Conv.* 1926 (27).

glasses plotted with respect to n_D and ν, where it is seen that most glasses lie on two well-defined curves, with the barium crowns lying chaotically outside; but if we plot c against n_0, as in the accompanying figure, it is seen that the glasses divide themselves up into three well-defined groups.



In the first line are the "old" glasses, in the lowest line are the "new" barium crowns, while in between lie the barium flints. It seems rather striking that the glasses are typified only with regard to the presence of barium in their composition.

As far as the writer is aware no physical meaning is attachable to the Hartmann formula, and none therefore to the relation between the constants.

DISCUSSION

Mr T. Smith: May I suggest to Mr Lee that he should add to his Table the values of the constants n_0, λ_0 and c for crystalline materials of optical importance—particularly fluorite?

As the formula is of the "four constant" type it is obvious that it can hardly be bad for interpolation within the narrow limits of the visible spectrum, nor will the fit be much affected by assigning to a the mean value for all glasses. The real test of such a formula is by comparison with observations at wave-lengths well outside the visible spectrum. The fact that observation within the visible spectrum is of very high accuracy justifies a test by extrapolation. Tests may be made in other ways—for example n_0 should be the refractive index for very long waves, and at wave-length λ_0 light absorbed. From this point of view the figures of the table suggest that the formula is not unlikely to disagree with observation sensibly in the ultra-violet, the increase in the index for many glasses being probably too

small. The choice of a formula, for use over such a small range as the visible spectrum, thus becomes a matter of convenience, and the Hartmann form seems less convenient than other expressions in which the functions of the wave-length are independent of all glass constants, and are the same for all glasses. Such formulae are not necessarily more greatly in error than Hartmann's expression for long and for moderately short wave-lengths outside the visible spectrum. Taking the glasses HC 4 and DF 4 from the author's table, the following values are obtained for $\lambda = \infty$ and $\lambda = \cdot 3\mu$ according to the formula of this paper and that given on p. 104 of Vol. 22 of these *Transactions*, which involves only the values of μ_D and ν for the glass:

		$\lambda = \infty$	$\lambda = \cdot 3\mu$
HC 4	H.W.L.	1·50070	1·55901
	T.S.	1·49663	1·55898
DF 4	H.W.L.	1·59234	1·70386
	T.S.	1·58824	1·71523

Mr J. W. Perry: In this interesting paper our attention is again called to the important question of wave-lengths for the standard specification of the refraction constants of optical media. This question is at present in a state of flux, and it is unfortunate that no general recommendation has been made, nor any determining orientation by general consent been given, to the modifications which are now gradually being introduced in different countries into the old-established procedure.

The replacement of the sodium D lines by the single D_3 line is indubitably an improvement in view of the serious disadvantages of the sodium burner, e.g. as regards its heating effects in accurate spectrometry, and in view of the great convenience of the helium discharge lamp. It is of some importance in practice that the necessary number of light sources should be reduced to a minimum, and it may for this reason be noticed that the mercury lamp and helium lamp or vacuum tube together provide suitable wave-lengths for the whole visible spectrum-range, as follows: He 7065, He 5875, Hg 5461, He 4713, Hg 4359, Hg 4047 Å.

The line λ 4713 Å, a line of moderate intensity, is here substituted for the F line. Incidentally, achromatism for $\lambda\lambda$ 7065–4713 is practically equivalent to orthodox visual primary chromatic correction; so that, assuming the acceptability of such a modification, what is possibly the last advantage of the outstanding third light source would appear to be circumscribed.

Mr Lee: The calculation of the Hartmann constants was undertaken to test the accuracy of the formula throughout the visible spectrum, with a view to extrapolation a short distance into the ultra-violet. The modern photographic plate is sensitive from the extreme red (even the infra-red) well into the ultra-violet region, and the designer is faced with the difficulty that his optical data end at a wave-length of 4000 Å. As measurements of refractive indices in the invisible spectrum are not likely to be of a high order of accuracy, extrapolation from an exact formula is likely to give results of sufficient accuracy.

I quite agree with Mr Perry that the helium and mercury tubes provide in themselves sufficient lines for the optician, but for the testing of a formula, the additional *C* and *F* lines are valuable; the change to achromatisation for λλ 7065–4713 should present no difficulties.

The Hartmann constants have been worked out for quartz and fluorite, using the data published in the Smithsonian Tables. The lines used for calculating the constants are 6867, *F*, and 3968.

	n_D	ν	n_D	c	λ_0	Errors in			$\lambda_0 + 1{\cdot}73\nu - 243{\cdot}3$
						C	*D*	*G'*	
Quartz (O)	1·54424	69·9	1·52825	25·5	119	− 4	− 5	0	− 3·4
Fluorite	1·43393	95·2	1·42455	15·0	119·8	− 6	− 4	.	+ 41·1

It will be seen that fluorite is a long way off the straight line connecting λ and ν in optical glass—hence its value in constructing microscope apochromats. It, however, lies almost exactly on the line of "ordinary" glasses in the figure, but quartz does not lie near any of them.

REVIEWS

Proceedings of the Optical Convention, 1926. Part I, 512 pp.; Part II, 578 pp. Fully illustrated, with plates and figures in the text. (London: The Optical Convention, 1, Lowther Gardens, Exhibition Road, S.W.7.) Price £3 net. Inland postage 1*s*. 3*d*. extra.

It may be said at once that these two volumes constitute a notable and valuable addition to the literature of applied optics. A comparison between the *Proceedings* of the 1st and 2nd Conventions, held in 1905 and 1912 respectively, and those of the present (1926) Convention will have a special interest for British workers in the fields of theoretical and applied optics. In the field of ophthalmological optics alone, the 1905 *Proceedings* contain 3 papers, reported on 19 pages; in 1912, 5 papers on 33 pages; whilst in the present *Proceedings* 10 papers, covering 120 pages, will be found. The increase in the worth of the papers is not less pronounced. In the branches of optics specially stimulated by war activities, such as the manufacture of optical glass, the general advance is even more marked.

The presidential address of Sir Frank Dyson opens with a brief sketch of the optical work done in this country during the momentous period of 1912–27, more especially as regards the production of the different varieties of optical glass. It is noteworthy that, whilst in 1912 only 10 per cent. of the glass used in this country was home-produced, this figure had risen to 95 per cent. for a production of nearly 9 tons per month in 1918. (The pre-war world's demand for optical glass was of the order of 20 tons per year.) Summing up the present position it is stated that "opticians can, and do, obtain, from British sources, all the optical glass needed, both in variety of type and excellence of quality."

The war-time production of such optical munitions of war as range-finders, periscopes, dial-sights, photographic lenses, etc., is dealt with.

Naturally, the history of the various optical instruments used by the astronomer in his work comes in for more detailed treatment. Observations with the simple non-achromatic telescope led up to two notable astronomical triumphs during the period embracing the end of the seventeenth and the beginning of the eighteenth centuries, namely, the discovery of (1) the finite velocity of light, from observations on the eclipses of the satellites of Jupiter, by Roemer in 1675, and (2) the aberration of light in 1725–6 by Bradley. "It is interesting to note that the finite velocity of light, and the aberration of light, discoveries of fundamental importance in physics, were made incidentally by astronomers engaged on their own problems, the movements of the satellites of Jupiter and the distances of stars."

So late as 1790, it is pointed out, "the largest and best" telescope (made by Peter Dollond) had an aperture of 5 inches only, and even so late as 1824, after Guinand and Fraunhofer had done so much work, the largest object-glass, made for the Dorpat telescope, had a diameter of 9·6 inches. A diameter of 25 inches, however, was reached in 1869, in the object-glass made by Messrs Cooke and Son for Newall.

The President refers finally in his address to the recent work of Michelson and Gale (1919), in measuring by an interference method "the tidal changes in the water level in two pipes, one north and south, the other east and west, 502 feet long." The tides thus mapped automatically and continuously for a year were "found to be 0·690 of what they would be on the rigid earth." In a more recent investigation by the same experimenters they determined the difference in time taken by light to pass in opposite directions around a rectangle (2010 × 1113 feet) of drain pipes exhausted of air, and obtained results consistent with a stationary ether, and therefore with the theory of relativity.

The first paper reported in the *Proceedings* is one by Prof. F. A. Lindemann on

"The main points of divergence between electromagnetic and quantum theory of light." The scope of the paper is set out by the author in these words: "It is common knowledge that the undisputed validity of the quantum theory as applied to matter, i.e. atoms, protons, electrons, etc., has little or no connection with its validity in the field of radiation. Whether this takes place according to the Maxwell equations, or whether these also must yield to a quantised emission theory, is still quite uncertain. The object of this paper is to state the arguments for and against the two points of view." This paper will be read with great interest by all students of physics, and especially by those who still *feel*—in the words of Sir Arthur Schuster—that "the problem of light will only be solved when we have discovered the mechanical properties of ether." Dr Lindemann says that "It is notorious that each theory is supreme and apparently unassailable within its own domain. The wave theory can, and does, explain all the facts of interference, polarisation, etc., the emission theory explains the interchanges of energy between radiation and matter. No explanation of even the simplest phenomena of interference has hitherto been able to dispense with the wave concept"; and yet again "The emission theory, of course, accounts without difficulty for all the facts relating to the interaction of radiation and matter which have proved a stumbling-block to the undulatory theory." How we should all like to have a peep into a text-book on light, written say in 1977, especially so if by that time, as suggested as possible by Prof. Lindemann, the description of physical phenomena in terms of mass, length, and time has been abandoned!

The papers in the first volume of the *Proceedings*, with which alone we are dealing at the present time, are concerned principally with (1) optical glass, (2) colour problems and apparatus, (3) illuminating and photometric apparatus, (4) the eye and its correction. A number of papers and notes on miscellaneous optical subjects are also included, notably a paper of fundamental importance on "Some visual factors affecting the use of optical instruments" by Prof. L. C. Martin.

Optical glass. A valuable paper on "Some recent developments in the art of production of glass for optical purposes" is given by Messrs W. H. S. Chance and W. M. Hampton. Lord Rayleigh has "Some notes on silica glass," whilst an interesting paper on "A method for the determination of the extinction coefficients of optical glasses for light in the visible spectrum" is given by Mr W. D. Haigh.

Colour problems and apparatus. These papers are appropriately prefaced by one by Mr J. Guild on "A critical survey of modern developments in the theory and technique of colorimetry and allied sciences." The paper includes an invaluable bibliography of some four pages. Amongst other authors Dr R. A. Houstoun describes "A new instrument for investigating colour vision," Prof. W. Peddie deals with "A colour vision spectrometer" and also with "The mathematics of colour vision, etc.," Mr Wm. Gamble writes on "Colour in relation to printing," whilst Dr S. G. Barker and Mr H. R. Hirst give a paper on "Colour problems in the woollen and worsted industries."

Illuminating and photometric apparatus. The papers in this section are mainly contributed by members of the research staffs of the National Physical Laboratory and of the General Electric Co. Dr Campbell and Miss M. K. Freeth give a paper on "Variations in tungsten filament vacuum lamps," which is prefaced by one by Mr T. H. Harrison on photo-electric cells. The use of electric incandescent lamps as sub-standards in photometric work is dealt with in one paper by Messrs B. P. Dudding and G. T. Winch, and in another by Mr W. Barnett. An account of work on searchlight illumination, carried out for the Admiralty at H.M.S. Vernon and Stokes Bay, is given by Mr S. Harcombe in "Illumination measurements of projected beams." Portable illumination photometers are dealt with by Mr A. K. Taylor, and the optical systems of ships' navigation lanterns by Dr E. H. Rayner.

The eye and its correction. This section starts off with an all-too-short abstract of a lecture by Prof. G. Elliot Smith on "The eye and its functions." The Northampton Polytechnic contributes its quota in a paper on "The transposition of obliquely crossed

cylinders," by Mr H. H. Emsley, and a paper on "The Mechanism of Accommodation," by Mr E. F. Fincham. Valuable collections of statistical tables are given by Messrs Owen Aves and W. Swaine.

The second volume of the *Proceedings* will be dealt with in a second notice.

F. J. C.

The Optical Convention, 1926: *Catalogue of Optical and General Scientific Instruments*. Pp. x + 319; numerous illustrations. (London: The Optical Convention, 1926.) Price 6*s*. net; Inland postage 9*d*. extra.

The catalogue of an Exhibition that is over and done with must have valuable features indeed if it is to retain much interest. The aim of the compilers of this three hundred page quarto volume was to persuade the various exhibitors to furnish, not a mere list of the more usual types of their products, but rather a description of improvements, and advances in instruments, effected since the last Convention of 1912.

The variation of response to this suggestion indicates the embarrassment which it must have caused in some quarters. In many cases there is a well-prepared account of real progress, but sometimes there is little of descriptive interest, the space being occupied by lists of uninteresting dimensions and vague generalities taken *en bloc* from the maker's trade catalogue. What purpose is served by a half-tone print of the *outside* of a photographic lens?

The form and composition of this, like other optical catalogues, is based to a great extent on an assumption of comparative ignorance of optical matters on the part of the reader and possible buyer; but this individual may not be so ready to buy a "pig in a poke" as is sometimes imagined. The buyer of even a cheap motor-car expects a great deal of very detailed information, the like of which could not be extracted under any persuasion from some opticians, who seem to have lost completely the art of attractive publicity based on cleverly stated facts.

Yet when this word of criticism (possibly attributable to unsatisfied curiosity) has been passed, we still have a most interesting volume giving a picture of real progress; no reader of the *Proceedings* should fail to secure it for reference. We see, for example, how the production of new types of optical glass renders possible new types of spectacles. The improvement in the diagnostic methods of ophthalmology is reflected in the sections giving particulars of new ophthalmoscopes, the slit lamp and corneal microscope, the Graves contact illuminator, and the like. Telescopes of all kinds come under review, from the new prism binoculars with apparent fields of 70° to astronomical instruments. We find some interesting particulars of the colour correction of new object-glasses.

The range of microscopes and accessories is one of the most remarkable features; the variation of design is a reflection of the different individual tastes still catered for in this country. Is the microscope still in course of evolution? In this connection, as in the succeeding section on photographic apparatus, it is abundantly clear that the limit has by no means been reached in purely optical design; the series of photographic lenses is a tribute to the powers of their computers; the same applies to the kinematograph projection lenses.

The following sections, on Interferometers, Spectroscopes, Refractometers, Photometers, Colour-measuring Instruments, and Surveying Instruments are those in which the provision of new descriptive material is most satisfactory. There is no doubt that the supply of fruitful ideas is still as free as ever it has been, if not more so. The historical section of the Exhibition, which will be, to many, one of its best memories, showed us how the true evolution of instruments has grown to be a quicker and quicker process. Some idea of the range of the historical exhibits, with many interesting details, can be gained from the Catalogue.

The sections on sighting and signalling apparatus, meteorological instruments, navi-

gational instruments and so on must be dismissed with a mere mention, as must the section devoted to experimental and research apparatus.

As a nation we may recognise with pride that some of the instruments described in this Catalogue are the best of their kind obtainable anywhere. The great lesson to be gained, in the writer's opinion, is that of the paramount necessity of constant effort towards the improvement in the design of instruments, an effort which should combine a wise conservatism with an open and scientific readiness to give the fullest consideration to new ideas and methods. We have plenty of ideas; if we have failed in some respects to exploit them fully, it is because we have not realised the value of team-work.

L. C. M.

Lens Computing by Trigonometrical Trace. By Col. GIFFORD, F.R.A.S., with a foreword by Prof. CHESHIRE, C.B.E. Pp. xii + 81; 18 Figs. (London: Macmillan and Co., Ltd., 1927.) Price 7*s.* 6*d.* net.

Col. Gifford's personal achievements in optical designing, together with his great experience of the application of the results of exact refractometry to computing problems, will command the greatest respect for any account of his methods. The booklet under review confines itself to the computing of telescope object-glasses and eye-pieces, although the same methods thus introduced will be of use in a far wider range of problems.

The first three chapters give an extremely elementary description of the action of prisms and lenses, together with an account of the measurement of refractive index by the spectrometer. Thereafter the book discusses achromatism, sign conventions, and spherical aberration; it then proceeds to the "lay-out" of lenses from selected glasses, and the usual methods of trigonometrical ray-tracing, examples of which are given in detail. Methods of employing calculating machines are also described.

No attempt is made to deduce the formulae used; the preface refers the beginner to Steinheil and Voit's *Handbuch der angewandten Optik*, or its translation in English, for the explanation of the methods; it would be hardly possible for a beginner to use this book alone. Even so it would have been desirable to include an intelligible explanation of the various criteria in discussing achromatism and other matters, and also to prove the formulae (due to Nelson) for the lay-out of eye-pieces which are quoted in Chapter X.

The only attention paid to oblique aberrations is contained in the arbitrary rule that "we have to bring both back and equivalent foci for all rays as nearly as possible into coincidence"; it is to be feared that the power of the computer to deal with practical problems in which "coma" and "astigmatism" have to be encountered would be extremely restricted, to say the least!

This book takes a few selected lenses and shows that suitably traced rays indicate small residuals of spherical and chromatic aberration. How far can it help the designer who has to use new glasses and new curves? How far can it help him to judge whether the aberrations found trigonomically are sufficiently small? An intercept of one-hundredth of an inch may be important under some conditions and negligible under others. While in one case p. 41, *et seq.*, it is shown how undesirable residuals of spherical and chromatic aberrations may be reduced, there is little indication of the method of conducting the systematic trials which are usually inevitable in the "trigonometrical" stages of a design. Apart from analytical guidance, the trigonometrical method only too often resembles the blind groping for a needle in a haystack. It has its uses in certain familiar types of problem, such as the present book discusses, but even so it is of very little use unless conducted on a systematic plan.

This book, then, takes the reader from the mere discussion of methods, found in Steinheil and Voit, into the sphere of practical problems; but the solution of these problems is a matter calling for a much longer journey.

L. C. M.

ABSTRACTS OF PATENT SPECIFICATIONS

255192. Trust Stocks and Shares Ltd., and another. VEHICLE LAMPS.

The reflector consists of upper and lower half-paraboloids, the latter set with its focal point a little in advance of that of the other. In the upper half of the lamp are placed one or more horizontal reflectors and an inclined reflector, the lower faces of which alone are silvered.

256004. Brebner, A. LAMPS.

A beacon or headlight has two or three mangin mirrors, preferably lying in planes at right-angles, arranged around a single source of light. The reflected beam from one of these mirrors is directly projected, while that from the others is reflected from separate plane or curved mirrors to reinforce the main beam, or to provide a multiple beam.

256197. Soc. C. G. Picard et Fils. VEHICLE LAMPS.

The front glass is provided with horizontal prisms of which one half consists of clear glass arranged to throw downwardly a beam of white light, while the other half is coloured, to project upwardly a tinted beam.

R. J. T.

CORRESPONDENCE

YOUR reviewer's criticisms* of the "international" definitions of the photometric magnitudes are not too severe. Indeed he might have made the verbal absurdity of the definition of luminous flux yet clearer by pointing out that, interpreted literally, it would permit the identification of the luminous flux from a lamp with the wattage marked on it by the maker, so long as the marking is read by the light of the lamp. Nevertheless the definition does contain a germ of sense, which should be developed when the "fresh start" is made.

The Commission define luminous flux with reference to two things, radiant energy and visual sensation. Now any satisfactory definition of a magnitude measured fundamentally must consist of two parts, a definition of equality and a definition of addition. It so happens—for surely a divagation into sanity on the part of this Committee can only have been accidental—that the two things correspond accurately to the two parts. Luminous fluxes are equal when they are equivalent in respect of a certain visual sensation (brightness, as distinct from colour); they are added in the same way as radiant energies. A full definition would require greater precision, but even such a short statement as this would probably be practically sufficient.

Of course the latter part of the statement is not strictly true of heterochromatic fluxes. But since no other definition of addition is any better for these, the conclusion is, as your reviewer indicates, that there is no such thing as luminous flux, measurable in all circumstances.

NORMAN R. CAMPBELL.

11th May, 1927.

* *Trans. Opt. Soc.* **28** 1926–27 (114).